ROBUST MULTI-SCENARIO OPTIMIZATION
OF AN AIR EXPEDITIONARY FORCE FORCE
STRUCTURE APPLYING GENETIC ALGORITHMS
TO THE COMBAT FORCES ASSESSMENT MODEL

THESIS

Barry D. Bennett Jr., Major, USAF

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DEPARTMENT OF THE AIR FORCE
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Maj. Raymond R. Hill, USAF, ENS, DSN: 785-6565, ext.4327, Ray.Hill@afit.af.mil

14. ABSTRACT

The United States Air Force is increasingly facing more diverse threat situations while existing force structure levels are being reduced and proposed compositions are being severely scrutinized for relevance, affordability, and effectiveness. Military planners are struggling with the question of how to generate a single force structure that can adequately respond to a multitude of threat scenarios in an uncertain future while at the same time being tasked to prove just how effective their choice will be. In the past, modeling has been effective in showing how a force can respond to a single threat scenario but a new modeling technique needs to be developed for constructing a robust force capable of success across a gambit of scenarios.

This thesis proposes a meta-heuristic approach to solving the planner's multi-scenario optimization problem. The approach makes use of an existing single scenario optimizer, the Combat Forces Assessment Model (CFAM), a public domain genetic algorithm, GENESIS, and a Visual Basic controller module to link them together. The approach is demonstrated by finding a robust AEF strike force tasked against three notional AEF threat scenarios.

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Barry D. Bennett Jr., B.S.

Major, USAF

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Barry D. Bennett Jr.
Major, USAF

Approved:

Raymond R. Hill
Major Raymond R. Hill (Co-Chairman) — 13 Mar 00
date

Lt Col Gregory A. McIntyre (Co-Chairman) — 13 Mar 00
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Barry D. Bennett Jr.

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Abstract

The United States Air Force is increasingly facing more diverse threat situations while existing force structure levels are being reduced and proposed compositions are being severely scrutinized for relevance, affordability, and effectiveness. Military planners are struggling with the question of how to generate a single force structure that can adequately respond to a multitude of threat scenarios in an uncertain future while at the same time being tasked to prove just how effective their choice will be. In the past, modeling has been effective in showing how a force can respond to a single threat scenario but a new modeling technique needs to be developed for constructing a robust force capable of success across a gambit of scenarios.

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I. Introduction

Thesis Overview

This chapter briefly presents the background, motivation, problem, and objectives in obtaining a robust multi-scenario force optimization for an AEF strike force. The discussion continues with an brief examination of the research approach, methodology, and scope of the thesis. Chapter two presents a synopsis from current literature of activities driving the development of the thesis methodology and of concepts germane to its formation and execution. Chapter three presents the thesis methodology in depth, while Chapter four discusses the implementation of the methodology on an experimental test case. The thesis concludes with a discussion on the research findings and recommendations for further research.

Background

Since the fall of the Soviet Union in 1989, the procurement and budgetary decisions facing the Department of Defense (DoD) have become more complex. We no longer have a well-defined and structured hostile super-power against whom to plan and structure a military force. The United States spent 40 years structuring its defense forces

to counter Soviet aggression and the last 10 years downsizing and living off the largess of the materiel developed during the cold war era. The budgetary effect of this downsizing trend on Air Force procurement and technology development can be seen in Table 1.

Table 1. Air Force Budget (Air Force Almanac, 1999:56)

Air Force Budget and Air Force Major Force Programs for the last 10 years
(Total Budget Authority in FY00 constant $ billions)

Air Force Budget	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99
Procurement	36.1	27.8	26.3	24.5	19.3	17.7	16.4	14.8	15.7	17.8
RDT&E	16.4	14.3	14.7	14.5	13.2	12.7	13.1	14.6	14.7	13.9

Percentage real growth	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99
Procurement	-5.6%	-22.9%	-5.5%	-8.1%	-20.2%	-8.3%	-7.3%	-9.5%	6.0%	13.1%
RDT&E	-11.6%	-12.9%	2.8%	-1.3%	-9.1%	-3.7%	3.5%	11.1%	0.8%	-5.3%

AF Major Force Programs	FY90	FY91	FY92	FY93	FY94	FY95	FY96	FY97	FY98	FY99
Forces										
Strategic Forces	15.6	14.6	12.2	9.7	6.2	5.1	5.1	3.9	4.4	4.1
General-Purpose Forces	25.6	24.4	20.4	18.4	17.6	16.9	16.9	16.6	16.8	16.5
Airlift Force	6.8	5.9	7	8.1	8.7	9.1	8.7	8.6	9	9.8
Support										
Research & Development	10.9	9.4	9	8.4	7.5	8.4	8.5	8.1	8.1	7.2
Central Supply & Maintenance	12.2	10.6	7.2	6.5	4.5	4.5	4.2	4	4	4.2

Although the defense budget has increased in the last two years, it has not kept pace with the demand for our forces throughout the 1990's. The United States has used air power more decisively, more frequently and in more unforeseen locations than ever before: DESERT STORM to NORTHERN and SOUTHERN WATCH in Iraq; peacekeeping in Somalia, Haiti, and Bosnia; deterrence in the Taiwan Strait and Korea; and intervention in Kosovo.

With the old enemy gone, budgets tight, fighting occurring more frequently and in more unforeseen situations, one can appreciate the problems force planners have in structuring and procuring a viable force. But these are not the only factors plaguing the

planners. More frequent conflicts, on several different levels of involvement, have led to changes in the very nature of how our forces are used. Naturally the more a weapon is used, the quicker experience is gained on the employment of that weapon. This leads to different methods of employment not only to make the weapons more effective but also to prevent the Air Force from being too predictable in the weapons use. However, this frequent use and change in employment only increases the planning difficulties since the conflicts occur on a shorter cycle (measured in weeks or months) with respect to time than the planning and budgeting cycle (measured in years). Weapons expended in engagements must be replaced in order to maintain adequate inventories for future engagements.

Replacing these weapons presents two main problems for the military planner. First, monies must be diverted from other existing, funded programs to pay for these replacement weapons. This diversion of funds causes delays, cost increases, and restructuring of the affected programs. In recent years, the affected programs most often have been modernization programs. The reprogramming of funds thus delays the acquisition of new weapons and weapons platforms at a time when existing weapon inventories are being depleted and large portions of the service lives of existing platforms are being expended. This leads to the second problem.

A simple replacement for the expended ordinance may not be possible or desired. Replacement is not possible, or at least prohibitively expensive, when the production line of a particular weapon system has been shutdown in order to free up funds for development of its replacement. The replacement system may have years to go in research and development before production models can be fielded. Replacement is not

desirable when post-conflict analysis indicates that an existing version of a weapon has operational deficiencies or new vulnerabilities to enemy countermeasures. This leaves planners in a quandary. Reopen a production line of a proven but dated weapon system to fill immediate shortages in inventory or gamble that a reduced inventory will be sufficient until production of an unproven, but potentially more effective new design comes online. An illustration of this changing nature of warfare can be seen with the use of precision-guided munitions over the last ten years.

DESERT STORM demonstrated the utility of precision-guided munitions (PGM). Targets can be eliminated utilizing fewer weapons, fewer sorties and with less collateral damage than if more conventional "dumb" munitions are used. Politicians in particular, realizing the value of PGMs, have increasingly advocated their use. Cruise missile and other PGM strikes are becoming tools of choice for defense foreign policy. Recent actions in Iraq (Operation DESERT FOX) and Kosovo (Operation ALLIED FORCE) are examples of the increasing reliance on air power and PGMs but also illustrate the increasingly restrictive rules of engagement (ROE) placed on military actions.

Rules aimed to minimize allied casualties are put into effect not only to preserve valuable military assets and personnel, but also to maintain a cohesive alliance with other countries. Morale of a multi-national alliance must be maintained and opponents must be denied the propaganda value of public trials of captured airmen or pictures downed aircraft on the evening news. Consider the US aircraft losses in Kosovo during operation ALLIED FORCE. The pilots of the F-117 lost 27 March 1999 and the F-16 lost 6 May 1999 were both rescued before the Serb forces could find them (Rolfsen, 1999a:10). However, Kosovo did get propaganda mileage from these losses. The video of the F-117

wreckage was shown on Kosovo TV and rebroadcast to the world by CNN. Tiny Kosovo, outnumbered by NATO air forces, managed to do something that Iraq could not do, shoot down a stealthy F-117. Worse yet, they did it on just the third day of the air campaign (NATO Operation Allied Force website, 21 June 1999).

ROEs are also designed to minimize enemy civilian casualties and collateral damage. Often air strikes occur in close proximity to enemy civilians or a besieged populace. Precision air strikes stress the PGM inventory but minimize damage inflicted on a civilian populace. Minimizing collateral damage also reduces the amount of humanitarian relief required after the conflict is over. Thus, limiting collateral damage is a significant factor in determining which aircraft and munitions are employed.

There is a lot of uncertainty regarding the scope and type of conflicts the United States will face in the 21st century. How then is the military going to structure its forces and procure the weapons it needs to successfully prosecute these future conflicts? It is clear that the selection of aircraft and munitions are tied directly to prospective engagement scenarios, but increasingly those prospective engagement scenarios are becoming more numerous and uncertain. The military cannot afford to buy or maintain the large force necessary to guarantee the most favorable outcome in all potential future conflicts. What the military needs is a "robust" force effective over a broad range of possible scenarios. The challenge is how to determine this robust force.

One attempt to counter uncertainty and relieve high operations tempo of our current force, is the Air Force's restructuring into an expeditionary aerospace force (EAF) with ten aerospace expeditionary force (AEF) units. Each AEF contains 120-150 aircraft representing a cross-section of Air Force weapon systems (EAF website, 14 Feb

2000). The question that arises is what aircraft and weapons mix is best for the EAF (*i.e.* what is a robust EAF) and how is procurement of this force going to be budgeted.

Currently, force structures and procurement must be adequate to cover two near simultaneous major theater wars (MTW) and one small-scale conflict (SSC). Kosovo demonstrated that military aircraft and munition assets were inadequate for two MTWs (Matthews, 1999b:22). Increasingly, budgetary limits force the military services to procure weapons for one MTW with the hope that these same forces and weapons will adequately cover the second MTW, or a SSC. The other hope is that the break between the two "near-simultaneous" MTWs will allow replenishment of expended weapon inventories. Long acquisition lead-times and the realities of the budgetary process are also forcing the services into procuring weapon platforms as a first priority and the weapons themselves second. This is just the opposite of how the desired procurement process is envisioned: given possible scenarios, select the weapons required to obtain the objectives, then determine the proper aircraft types and numbers necessary to deliver the selected weapons in the time allotted.

A recent Air Force Times article (Matthews, 1999a:8) states that the 2000 defense authorization bill has language requiring a quadrennial defense review (QDR) to determine whether the nation's military is adequate for carrying out the nation's defense strategy. In particular, Congress wants the review driven by the demands of strategy, not by any presupposition about the size of the defense budget. DoD will examine defense strategy and various force structures suitable to carrying it out. If forces are inadequate, Congress wants to know what risks are involved and what additional forces are needed to mitigate those risks.

Three types of force structuring scenarios, EAFs, MTW-planning, and QDRs, all contain a similar challenge: how to structure a robust force for an uncertain future. Each scenario type suggests the need for analytical methods to determine robust solutions in multi-scenario planning processes.

Problem Statement

In many analytical settings the military services, and in particular the Air Force, must make force structure decisions to meet an uncertain future. The types and number of aircraft and munitions requested must be adequate to meet the foreseeable needs of the service and the nation. The numerous and diverse conflicts involving the United States in the last ten years have shown just how unpredictable the foreseeable future can be. The question is how to determine an adequate force in an uncertain future? This thesis proposes a methodology for determining robust solutions to military force planning problems. This methodology is demonstrated by considering the problem of determining a robust strike force component of the new AEF structure. Notional structuring alternatives and conflict scenarios are employed using the Combat Forces Assessment Model (CFAM).

Research Objective

The objective of this research is to demonstrate a workable methodology for determining a robust AEF strike force structure to satisfy a multi-scenario conflict problem. The qualifier robust specifies that the selected strike force has an inherent ability to do well in a range of situations. The overriding assumption is that the

methodology can be scaled up for larger force structure analyses over more scenarios. Such a methodology would be useful in the planning and budgetary exercises needed to show the functional utility of a service's proposed force and procurement requests during efforts such as annual budget reviews or the upcoming 2001 QDR.

Approach Methodology

The approach used is diagramed in Figure 1. The overall objective is to find a robust force structure. The specific objective of the approach is to identify an AEF force structure that maximizes some objective function value defined over a range of three notional engagement scenarios. Each candidate AEF force structure is examined using CFAM against each notional scenario. The output of each CFAM run is translated into a scenario objective function value. This value provides a measure of the force structure's ability to meet scenario demands. The evaluations for each scenario are combined into an overall measure, a measure of a force structure's ability in the multi-scenario space. A meta-heuristic search algorithm guides selection of candidate force structures in this multi-scenario space. A Genetic Algorithm (GA) is the meta-heuristic used to guide the search. The GA returns the best solution found by the search, a solution we define as the robust solution.

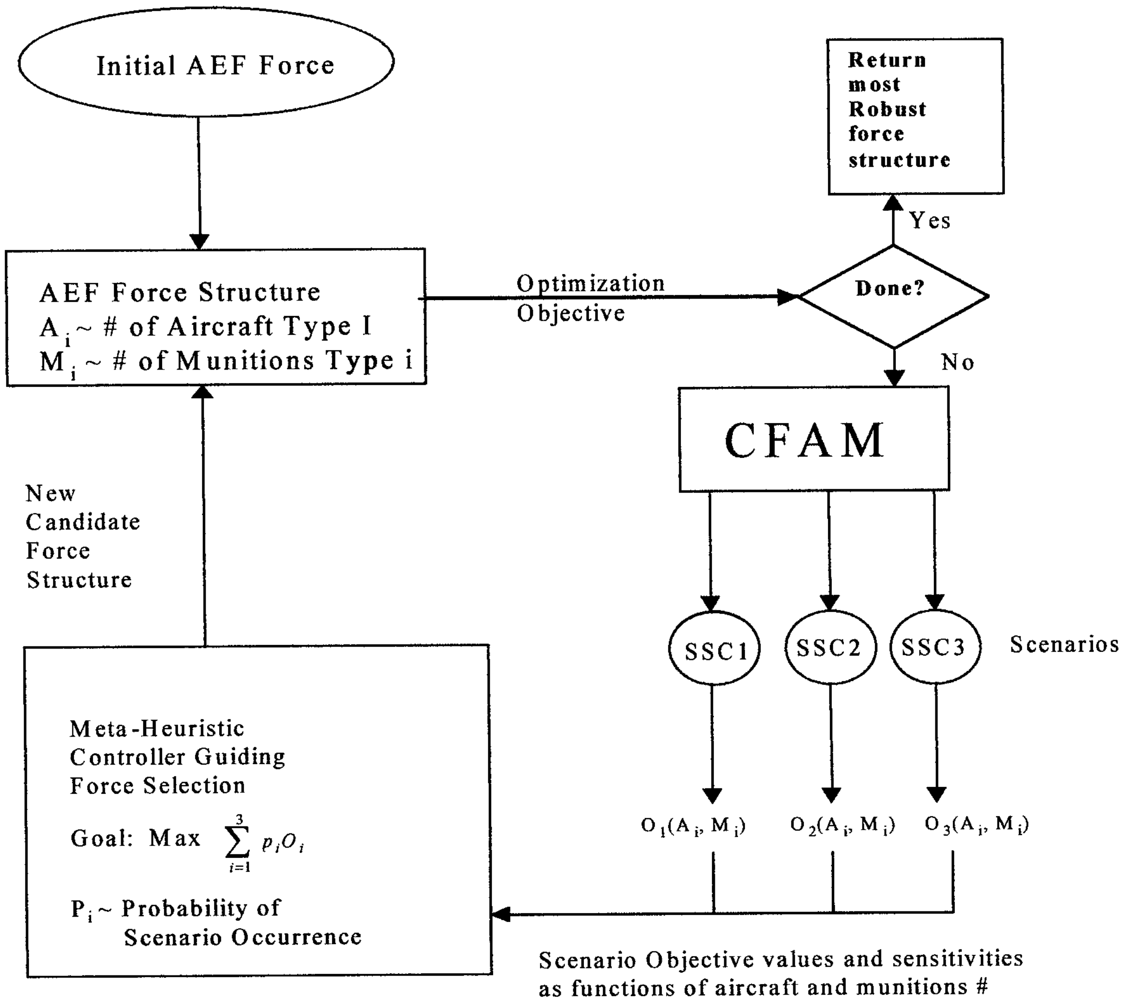

Figure 1. Research Approach

Scope

This thesis considers an AEF sized force structure tasked against three potential, seven-day duration, SSC scenarios. Though a relatively small problem, it is sufficiently challenging and realistic to exercise and demonstrate the methodology. An AEF structure is selected because of the U. S. Air Force EAF emphasis. A SSC is considered in lieu of a MTW, due to its increased likelihood and the recent experience in Kosovo

with its high amount of visibility. It is assumed the methodology developed and demonstrated can be scaled up to more realistic applications.

The AEF force structure methodology demonstrated in this thesis utilizes the existing Air Force Studies and Analyses Agency's (AFSAA) model CFAM to evaluate the effectiveness of candidate force structures.

II. Literature Review

Quadrennial Defense Review

The Quadrennial Defense Review (QDR) is conducted every four years during the inaugural year of a new presidential term in office. The QDR, "...will help the new presidential administration and Congress determine the defense strategy of the United States and establish a defense program over the next 20 years," (Air Force News web page, 2000). The Fiscal 2000 Defense Authorization bill has language requiring a quadrennial defense review to determine whether the nation's military is adequate for carrying out the nation's defense strategy. Congress wants the review to be driven by the demands of strategy, not by any presupposition about the size of the defense budget. DoD is to examine defense strategy and various force structures suitable to carrying it out. If forces are inadequate, Congress wants to know what risks are involved and what additional forces are needed to mitigate them (Matthews, 1999a). With the stated demand to determine the adequacy of force structures during the 2001 QDR, an upgraded version of the methodology presented in this thesis may be beneficial.

EAF and AEF Concepts

In October 1999, the U. S. Air Force entered the EAF era (Rolfsen, 1999b:17). The EAF concept represents a change in the U. S. Air Force culture and how it responds to conflicts. In the past ten years, the Air Force has changed from primarily a garrison force to an expeditionary force. The drawdown of forward-deployed forces and the elimination of many bases on foreign soil require the deployment of CONUS based

forces to respond to military and humanitarian crisis abroad. Not only are these forces deployed from CONUS but in many cases, are sustained from there as well. This has led the Air Force to restructure and form 10 AEF units that are: capable of rapid response, precise in application of force, situationally aware, secure, evolvable, and most importantly, light (Fuchs, 1997:1-2).

As originally envisioned, a typical AEF package would be vulnerable for deployment over a 90-day period and comprise approximately 30 aircraft (12 air superiority, 12 strike, and six suppression of enemy air defense (SEAD) fighters) capable of deploying within 24 hours and conducting air operations within 48 hours of receipt of the execution order. Depending on the availability of in-place theater assets, tankers and other assets would also be attached (Looney; 1996:1). However, this vision has been tempered by recent conflict. By late 1998 the number of aircraft assigned to each AEF had grown to 175 (Peters, 1998:6).

Recent experience in Kosovo has indicated a need to change the way the AEF aircraft and weapons mix are structured and procured. Low-density, high-demand aircraft assets such as EA-6B Prowlers, Joint-Stars, AWACS, and Compass Call are required in almost every deployment but insufficient inventory equates to high operational tempos for the unit personnel and excessive wear on the airframes. Nearly exclusive reliance on PGMs in Kosovo virtually exhausted PGM inventory. The desire for an AEF to be precise, lethal, and light will only drive the requirement for PGMs higher. This demand has further consequences for Air Force planning and procurement. Munitions are procured using the Capabilities-Based Munitions Requirements (CBMR) Process. The CBMR process must focus on meeting the requirements of the engagement

scenarios forces are expected to meet. In order to properly forecast the munitions requirements, guidance must be received on the expected engagement scenarios including projected likelihood of occurrence, rules of engagement, enemy forces expected, and numbers and type of enemy targets to hold at risk. Without the proper guidance, munitions and weapon platform programming cannot directly address risk and adequately justify procurement decisions. Services are left to fill the void as best they can with no hope of a consistent procurement policy (Yost, 1999:2).

CFAM

AFSAA's CFAM is the Air Force's current model used to size a force structure to respond to a single theater scenario. CFAM is a large-scale, linear program (LP) designed to provide decision makers with an analytical tool for determining the impacts of budget, attrition, force structure, targeting decisions, and munitions inventories on war fighting capabilities (AFSAA, 1997:3). It replaced three earlier models, Heavy Attack, Theater Attack Model (TAM), and Mixmaster, previously used to address munitions tradeoffs, allocations, and requirements.

CFAM can be set to optimize one of five possible objectives: (1) Maximize goal achievement; (2) Minimize attrition to meet time goals; (3) Minimize cost in a single budget to meet time goals; (4) Maximize the value of targets destroyed; and (5) Minimize time to meet campaign phase goals (CFAM99, 1999). Some of the problems CFAM can address include optimal mix of weapons at various procurement budget levels, affordable force structure at various budget levels, and preferred additional weapons or aircraft at specific budget levels.

Currently there are three variants of CFAM: Quick Strike, Time Strike, and Air Strike. Quick Strike permits optimization within the distinct time periods of an air campaign such as day-to-day. Time Strike optimizes across the entire air campaign. Air Strike, the newest variant, permits optimization across different planning and execution time frames. For example, in the Air Strike variant you can plan in nine-day intervals and execute/optimize for just three days. Details on general CFAM use and its formulation are found in Combat Forces Assessment Model Training Manual (AFSAA, 1997). Details particular to the Quick Strike variant can be found in The QUICK STRIKE Munitions Optimization Model (Rummer, 1997).

Exploratory Analysis

Exploratory analysis (EA) is a modeling methodology that expands upon other modeling approaches to provide more insight into the trends and tradeoffs involved with a problem (Bankes, 1993:203). EA searches for robust solutions across plausible parameter values, scenario conditions, decision options, and measures of effectiveness. The application of EA to the weapons mix problem (Brooks, 1999:67) is a prime example of how this type of analysis can benefit policy makers. We can make a general comparison between traditional and exploratory analysis of the weapons mix problem by comparing the sensitivity analysis available under both approaches.

Traditional analysis works from a single-point solution. This limits the range of sensitivity analysis application. Exploratory analysis, on the other hand, looks from the outside in. It generates a broad range of outcomes and allows a more comprehensive sensitivity analysis over a wider range of effects. For example, a traditional approach to

a weapons mix problem will identify an optimal solution with specific numbers of weapons to procure. Traditional LP-based sensitivity analysis provides information about weapons worth and targeting benefits but little on alternative solutions or solution trends. EA can possibly identify multiple optimal solutions (or near optimal solutions) and contributory trends applicable to a range of solutions. The enhanced sensitivity analysis available with EA makes trends more visible to the analyst and policy maker. Increased options, visibility of important interactions, and the ability to give the policy maker a "feel" for the underlying solution structure makes exploratory analysis extremely valuable to the policy maker. The problem however is that EA does not scale efficiently to multi-scenario situations. EA requires a good amount of computational resources even in the single scenario applications used to date.

Optimization Models

Robust Optimization

The goal of robust optimization (RO) models is to find solutions that are relatively immune to uncertainty in the problem parameters (Bai and others, 1997:896). Uncertainty in problem parameters is endemic in many real-world complex problems such as personnel planning and manufacturing. For instance, in manufacturing problems, parameters such as product demand, worker productivity, and worker availability are unknown. Often the only basis for formulating a problem's objective function is a decision maker's subjective estimate. At best, some past history can be utilized to narrow the degree of uncertainty but non-linear functions are not uncommon. Adding constraints

such as in sensitivity analysis may help but not in complex problems (Bai and others, 1997:898). Bai, *et al*, further states,

> "RO models have nonlinear objectives to capture risk aversion in decision making under uncertainty....there are several commonly held arguments against using nonlinear objectives. Three of them are: 1) it is difficult to determine a decision maker's utility function; 2) nonlinear utility functions may be well-approximated by piecewise linear function; and 3) nonlinear objectives yield mathematical problems that are more difficult to solve and require more sophisticated software."

Bai, *et al*, makes the argument that while nonlinear objectives, such as used in RO, are generally harder to solve, RO models capture uncertainty in their formulation. Linear models may not be able to capture the same uncertainty.

In RO, Bai, *et al*, uses scenarios to represent uncertainty. Each scenario represents a possible set of outcomes and yields a different scenario value, ω_s. Combining these values with some weight can generate an objective value across the range of uncertainty represented by the scenarios. An objective value across the scenarios is represented mathematically by

$$\sigma(\omega_1, \omega_2, .\omega_s) = \sum_{s=1}^{S} p_s \omega_s \tag{1}$$

where p_s is the probability that scenario s occurs.

The approach used by Bai, *et al*, generates an objective value across a range of scenarios based on a combination of individual scenario objective values. However in the real world, scenarios often have multiple, conflicting objectives. In this situation, another approach is needed to generate the single scenario objective value before Bai's approach can be used.

Multiple Criteria Decision Making

Real world decisions typically have to be made in the face of multiple, and often competing, objectives. The thesis example of an AEF strike force is an illustration of this type of decision-making. In decisions pertaining to the constitution of an effective AEF strike force, a few of the multiple, competing objectives include:

- Allow a wide variety of target types to be held at risk while using a range of weapons.
- Maximize the number of targets hit in the shortest possible time.
- Minimize the number and cost of aircraft used.
- Minimize aircraft and pilot losses.

Competing objectives make decision-making hard enough when determining a strike force for one engagement scenario. The difficulty increases when the same force is used over multiple scenarios.

The field of study devoted to finding solutions to multiple criteria situations is called Multiple Criteria Decision Making (MCDM). R. Ramesh and Stanley Zionts categorize the solution methodological approaches into four categories: deterministic decision analysis, stochastic decision analysis, multi-objective mathematical programming, and other explicit decision space methods (Ramesh and Zionts, 1996:421). The category germane to this thesis effort is deterministic decision analysis.

Ramish and Zionts define deterministic decision analysis as, "…concerned with finding the *most preferred* alternative in decision space by constructing a value function representing a decision maker's preference structure, and then using the value function to identify the most preferred solution." Note that they were careful to denote the solution

as "most preferred" rather than an optimal solution. MCDM is based on making tradeoffs between competing objectives using a value or utility function based on a decision maker's preferences. With multiple objectives, there is rarely a single solution that can simultaneously optimize all the objectives. Therefore, the emphasis placed on noting the solution as "most preferred."

Mutual preferential independence occurs when a decision maker's preferences in regards to a criteria's set of objectives is independent to his preferences in regards to any other criteria's set of objectives. A value function based on these preferences can be expressed mathematically in the form:

$$v(d_i) = \sum_{k=1}^{m} \lambda_k v_k (C_k^i) \tag{2}$$

where λ_k is a scalar constant (Keeney and Raiffa, 1976:111).

This value function formula simply states that the value of a candidate decision d_i is equal to the linear combination of m criteria value functions, $v_k(C_k^i)$. Each of the m criteria has a value function based on a set of objectives, C, germane to that criteria. A new decision candidate will affect the sets of objectives and change the result of the value function. When the problem at hand requires the selection of the best candidate from a set of decision candidates, the selection can be determined by selecting the candidate with the highest evaluation.

Heuristics

The solution space to a multi-scenario problem is a composite of the scenario solution spaces. This composite multi-scenario solution space requires a method to efficiently search this space for the desired solution. There is no guarantee that the composite solution space will be smooth and convex, even if its individual component solution spaces were convex. The search method employed must be equally able to search through rough and non-convex spaces. Heuristic search methods such as Genetic Algorithms work well for this type of solution space.

Genetic Algorithms

Genetic Algorithms (GA) are adaptive methods motivated by the evolution of biological organisms in the natural world, where populations evolve according to the principle of natural selection and "survival of the fittest." They are used to solve search and optimization problems (Beasley, 1993:58). The essential elements of a GA are a population of individuals, a population dynamic, a survival of the fittest selection rule, and an inheritance method. The population of individuals represent a set of possible solutions to a given problem. The population dynamic equates to the natural world's birth and death cycle. New individuals (offspring) are created via reproduction between mated pairs of individuals (parents) in the current population and old, weak individuals are killed off. The survival of the fittest selection rule is the method which determines the value or fitness of an individual. An individual's fitness is what determines the individual's chance to breed or die. Inheritance in GA is where traits parents are passed to offspring. The canonical GA algorithm, shown in Figure 2, shows how, in general,

new populations (generations) are created. Individuals are born, get assigned a fitness, compete for a mate, reproduce, and then die to make room for their offspring.

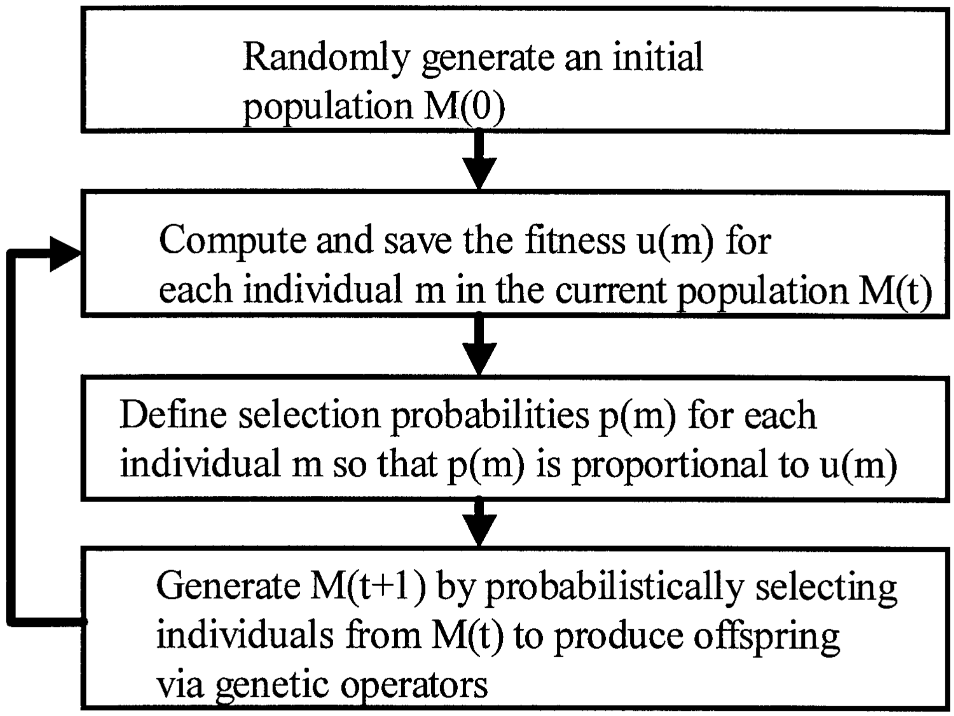

Figure 2. Canonical GA Algorithm

Before a GA can execute, a representation or coding of the individual must be made to fit the problem. Each individual or chromosome is a possible solution to the problem. Every chromosome consists of an ordered set of genes equating to a coded (usually in binary) set of problem parameters. The coded set of genes (the collection of 0s and 1s) is called the genotype. The problem specific meaning for that genotype is called the phenotype. For example, we have the following set of genes:

$$V_1 = (\underbrace{001100}_{A_1}\underbrace{000000}_{A_2}\underbrace{000110}_{A_3}\underbrace{010010}_{A_4}\underbrace{000000}_{A_5}).$$

V_1 is the genotype and is just a set of coded 0s and 1s. However, it becomes a phenotype when the set of 0s and 1s is assigned a meaning with respect to the problem. For this

thesis, the meaning we assign to V_1 is a strike force consisting of a number of five types of aircraft (A_1 through A_5). Note that the phenotype is domain specific; its meaning depends on its context with respect to the problem. The genotype is domain independent. It cares nothing about the problem context. This is one of the main benefits of GA. It works on the coding of the problem, making GAs a very robust technique (Reeves, 1995:179).

Two individuals reproduce by sharing some features, with the most fit individuals generally reproducing the most often. Over succeeding generations, the population becomes more homogenous, more fit, and contains individuals consisting of the "best" genes. These later generations should converge to a set of best though not necessarily optimal solution(s).

Before mating can occur some process must exist to select the parent. Generally selection is proportional to the fitness value assigned to the individual. Some examples of selection methods include tournament, rank, and proportional selection. In tournament selection, a random sample is taken from the population and the most fit individual in that sample is chosen to be a parent. Another sample is taken to obtain the other parent. This process continues until the entire mating population is chosen. In rank selection, the probability of selecting an individual is proportional to its index to the population. For example, in a population of size N the most fit individual would have an index of N-1 and the least fit individual would have an index of zero. Grefenstette gives a word of caution (Grefenstette, 1990:4), "Ranking helps prevent premature convergence by preventing 'super' individuals from taking over the population within a few generation. However, ranking often produces slower improvement than proportional selection." In proportional

selection, the probability of choosing an individual is proportional to its fitness with respect to the population as a whole.

Two important GA operators are called crossover and mutation. In crossover, the genes of the parents are split at certain locations and the resulting segments are swapped to produce new offspring. In mutation, a random gene in an offspring is flipped. This introduces additional diversity into the population.

An example of a proportional evolution process is listed below (Michalewicz, 1996, 34):

- Calculate the fitness value *eval(v_i)* for each individual in the population.
- Find the total fitness of the population
  - $$F = \sum_{1}^{i} eval(v_i) \quad (3)$$
- Calculate the probability of a selection p_i for each individual v_i :
  - $$p_i = eval(v_i) / F \quad (4)$$
- Calculate a cumulative probability, q_i, for each individual v_i:
  - $$q_i = \sum_{j=1}^{i} p_j \quad (5)$$
- Select individual to mate by generating a random number r from the range [0,1]. If $r < q_1$ then select the first individual v_1; otherwise select the i^{th} individual v_i such that $q_{i-1} < r \leq q_i$. Continue until the number of mated pairs equals half the population size.
- Each mated pair will reproduce using the crossover operator and the probability of crossover p_c. For each pair, generate a random number r from the range [0,1]. If $r < p_c$, then crossover will occur; otherwise, two offspring identical to the parents will result. If crossover occurs, then generate a random integer number from the range [1,m-1] where m is the total length of the individual in bits. Crossover (single point) will occur at the selected bit.
- Once the offspring are produced, the next operation, mutation, is performed on the offspring. The probability of mutation p_m gives the expected number of mutated bits p_m*m*population size.* Every bit in the offspring has an equal chance to mutate. For every offspring and for each bit within the individual:
  - Generate a random number from the range [0,1].
  - If $r < p_m$, mutate the bit (i.e. a 0 will become a 1 and vise versa).
- Now a new population, consisting of the offspring, is ready for evaluation.

Once a population has reproduced, some members of the pool of individuals must die off. Several methods exist but two have been used with particular success in studies, generational GA and incremental GA (Reeves, 1995:166). In generational GA a proportion *G* of the population is allowed to reproduce and then their offspring are allowed to randomly replace individuals in the current population. A population gap of one ($G = 1$) has been shown to be particularly successful. In incremental GA, a new offspring randomly replaces an individual from those that have currently below-average fitness. Incremental GA has an advantage over generational GA in that it is usually easier to implement and saves computational resources by preventing the occurrence of duplicate individuals.

Both population methods can be enhanced using an elitist strategy. In a simple implementation of GA, there is no guarantee that the best member of a population will survive into the next generation. An elitist strategy always carries the best individual into the next generation.

Two important population considerations are population size and the selection of the initial population. If the population size is too small, the GA can prematurely converge to a sub-optimal solution. If the population is too large, then many generations may be required for convergence. Many authors report empirical results indicating that population sizes as small as 30 may be adequate (Reeves, 1995:165). Other works suggest that populations between n and $2n$ will suffice where n is equal to the number of bits used to code the genotype.

An initial population is generally chosen at random. However, some experimental studies have shown that seeding a population with high-quality solutions,

possibly found through some other heuristic, can help a GA convergence quicker than the one with a random starting population. There are also opportunities to employ domain or problem specific knowledge to create high-quality, yet random populations (Hill, 1999:544). The quicker convergence comes at the cost of an increased possibility of premature convergence (Reeves, 1995:165).

According to Beasley, *et al.*, (Beasley, 1993:58), the GA is a robust technique. Since a GA works on a coding of a problem, a GA program can solve many different optimization problems. The GA simply needs the ability to calculate some measure of performance or fitness for each individual. However, since the GA is a heuristic, it does not guarantee finding an optimal solution, although empirical evidence shows that it does find "good" solutions to problems "relatively quickly."

Evolution Example

To clarify the evolution process, consider a simple example with 10-bit individuals and a $G = 1$ population gap. Let the initial population consist of four individuals:

$v_1 = (1111111111)$,
$v_2 = (0000011111)$,
$v_3 = (1111100000)$,
$v_4 = (0000000000)$.

Let their fitness values be:

$eval(v_1)=15$,
$eval(v_2)=10$,
$eval(v_3)=5$, and
$eval(v_4)=2$.

The total fitness of the population is $F = \sum_{1}^{4} eval(v_i) = 32$ and the resulting normalized probability of selection are $p_1=0.47$, $p_2=0.31$, $p_3=0.16$, $p_4=0.06$. The resulting

cumulative probabilities are $q_1=0.47$, $q_2=0.78$, $q_3=0.94$, *and* $q_4=1$. Four random numbers are generated (r = 0.01, 0.85, 0.58, 0.48). The selected individuals are v_1, v_3, v_2 and v_2. Two mated pairs result:

$v_1 = (1111111111)$,
$v_3 = (1111100000)$,

$v_2 = (0000011111)$,
$v_2 = (0000011111)$.

Let $p_c = 0.9$, and $p_m = 0.01$, and let crossover occur for the first pair, after the eighth bit:.

$v_1 = (\mathbf{11111111}|11)$,
$v_3 = (11111000|\mathbf{00})$.

Then the resulting offspring are:

$v'_1 = (\mathbf{11111111|00})$,
$v'_2 = (11111000|11)$.

The four offspring are now:

$v'_1 = (1111111100)$,
$v'_2 = (1111100011)$.
$v'_3 = (0000011111)$,
$v'_4 = (0000011111)$.

Since there are 40 bits among the four population members, 40 random numbers are drawn to determine whether any bit mutates. Let the mutation rate be $p_m = 0.01$. If the results of 40 random numbers indicates only the 35th, will mutate, only that bit is flipped from 0 to 1. The resulting population is:

$v'_1 = (1111111100)$,
$v'_2 = (1111100011)$,
$v'_3 = (0000011111)$,
$v'_4 = (0000\mathbf{1}11111)$,

with respective fitness values:

$eval(v'_1)=13$,

$eval(v'_2)=17,$
$eval(v'_3)=10,$
$eval(v'_4)=7.$

The process continues for each subsequent generation.

Iteration Stopping Criteria

After successive generations, the average fitness level of the population should increase. Indeed the whole idea behind GA is to evolve to a population with solutions "close" to the optimal solution. However, the question of how many generations is enough remains. There are two ways to stop the GA, detect convergence or after a specific number of iterations (*i.e.* generations).

If the rate of fitness improvement over successive generations falls off then the population may have converged. Beasley (Beasley, 1993:60), expanding on earlier work by DeJong, defines convergence as, "The progression towards increasing uniformity. A gene is said to have converged when 95% of the population share the same value. The population is said to have converged when all of the genes have converged." One will recognize convergence if, as the population evolves over the generations, the fitness of the best and the average individual in each generation increases towards some optimum.

Summary

Multi-scenario analyses, such as the required 2001 QDR, provide the impetus for a robust, multi-scenario, optimization methodology. Selection of an AEF strike force is apropos since an AEF, by definition, must be responsive to a variety of potential scenarios.

A robust force structure search methodology merges robust optimization and multiple criteria decision-making (MCDM) techniques. CFAM is a large-scale LP and can evaluate force structure performance in defined scenarios. These values can form the scenario objective values used in a multi-criteria function to generate a multi-scenario value function. A Genetic Algorithm is a robust technique for searching complex solution spaces such as the multi-scenario solution space facing DoD analysts.

III. Methodology

Introduction

This chapter describes the methodology used to find robust AEF strike force structures. The methodology has three main components: a Genetic Algorithm (GA), the Combat Forces Assessment Model (CFAM), and a combination Visual Basic/DOS routine. The GA component generates candidate force structures. CFAM is used to determine the fitness of that candidate force structure. The Visual Basic/DOS routine is the data manager. It receives the force structure from the GA, modifies the CFAM input files, calls for the CFAM evaluation, combines the output files to generate an overall evaluation value, and then transfers the value back to the GA. The methodology is depicted in Figure 3.

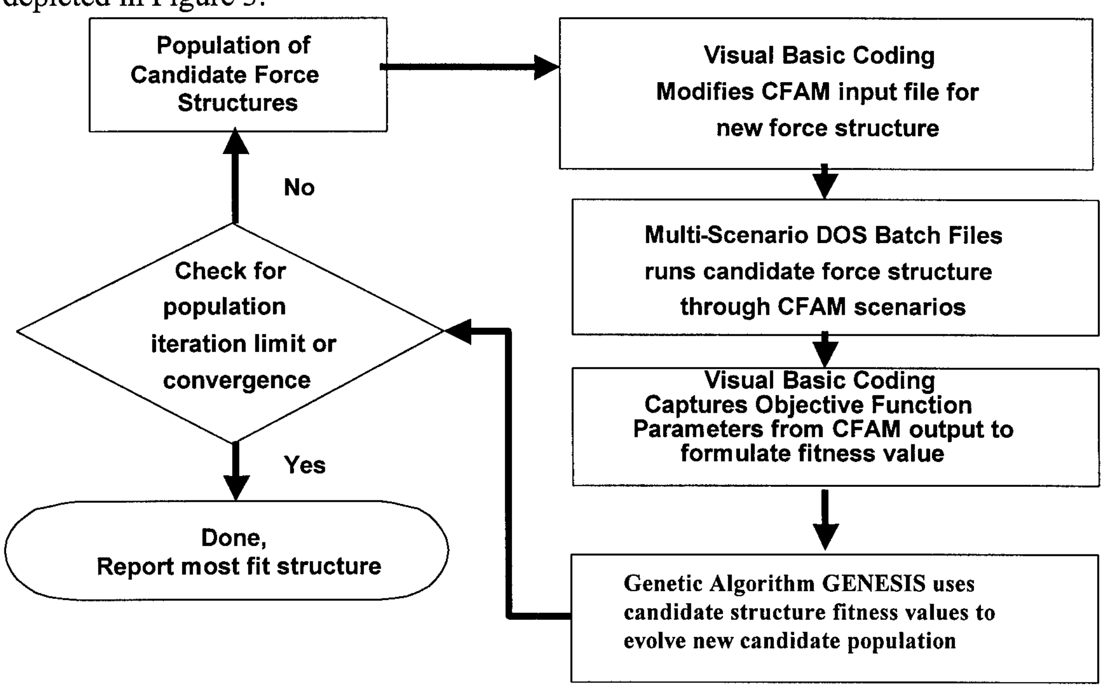

Figure 3. Robust Optimization Methodology

Genetic Algorithm Meta-Heuristic

Genotype Structure

The candidate force structure consists of values of five different types of aircraft encoded into a genotype, or a binary representation upon which the GA acts. The genotype used in this thesis consists of a 30-bit binary number consisting of five genes. Each gene represents the number of strike aircraft of a particular type to include in the force structure. The maximum number of strike aircraft included in a candidate force structure gene, or aircraft type, is limited to 63. Since the number of each aircraft type is restricted to the range of 0 to 63, the aircraft quantity requires a gene six-bits long. For example, if 12 strike aircraft are encoded, then the gene would be appear as $x_1 = 001100$. Using the same notation found in Chapter II's GA evolution example, a sample individual from the candidate population would be represented as follows:

$$V_1 = (\underbrace{001100}_{A_1}\underbrace{000000}_{A_2}\underbrace{000110}_{A_3}\underbrace{010010}_{A_4}\underbrace{000000}_{A_5}).$$

V_1 is a force structure consisting of A_1 = 12 type-one aircraft, A_2 = zero type-two aircraft, A_3 = six type-three aircraft, A_4 = 18 type-four aircraft, and A_5 = zero type-five aircraft.

Evolution and Evaluation

The particulars of the GA are embedded in a public domain algorithm, GENEtic Search Implementation System (GENESIS Version 5.0) written by John Grefenstette (Grefenstette, 1990:3). GENESIS follows the same basic GA steps listed by Michalewicz in Chapter II. After an initial population is generated at random, the population is evaluated using a specially constructed evaluation routine (Appendix 1),

which calls the Visual Basis/DOS subroutines to run the scenarios in CFAM/GAMS and return a force structure evaluation. GENESIS uses this evaluation as the structure's relative fitness value. Table 2 specifies the parameters of the GA operators and implies that the number of generations is approximately equal to the total trials divided by the population size.

In the case of the input file in Table 2, GENESIS will proceed for at least ten generations. Runs of more than ten generations can occur with this input file when offspring identical to their parents are produced. The default setting in GENESIS is to not evaluate these offspring or count them as a valid evaluation trial. However, offspring identical to their parents are valid members of new populations and therefore factors in the determination of the number of generations experienced in the experiment. So when the number of evaluation trials reaches 300, there may have been more than ten generations generated. Additionally, GENESIS only terminates between generations. If after 300 trials, a partial generation exists, additional trials are conducted to complete the generation.

Table 2. GENESIS GA Input File

```
Experiments = 3
Total Trials = 300
Population Size = 30
Structure Length = 30
Crossover Rate = .9
Mutation Rate = .01
Generation Gap = 1.0
Scaling Window = 5
Report Interval = 30
Structures Saved = 10
Max Gens w/o Eval = 2
Dump Interval = 30
Dumps Saved = 1
Options = cedDfgMLoO
Random Seed = 252519393
Rank Min = 0.75
```

GENESIS allows several options to be specified in the input file (Options in Table 2). Table 3 decodes the Options field found in Table 2.

Table 3. GENESIS Options Field Definitions

Action Performed in GENESIS	Option Identifier
Collects statistics concerning the convergence of the algorithm.	c
Selects the "elitist" selection strategy for use.	e
Dumps the current population to "ckpt" file after each evaluation.	d
Performance statistics are printed to the screen after each generation.	D
Selects floating point representation.	f
Use Gray code.	g
Maximize the evaluation function	M
Dump the last generation to the "ckpt" file. This allows the experiment to be restarted at a latter time.	L
At end of experiment, write the average online performance measure to the standard output.	o
At end of experiment, write the average offline performance measure to the standard output.	O

After GENESIS executes, a series of output files are produced. Raw output data is sent to *out.tst* and the values of the global variables, including the final population are sent to *ckpt.tst*. The 10 best structures are sent to *min.tst* where each structure, its evaluation, generation of first occurrence, and trial of first occurrence are identified.

Combat Forces Assessment Model (CFAM)

CFAM is a large-scale, linear program (LP) designed to provide decision makers with an analytical tool for determining the impacts of budget, attrition, force structure, targeting decisions, and munitions inventories on war fighting capabilities (AFSAA, 1997:3). The force structure effectiveness measure used in this thesis combines five standard CFAM outputs into a single, multi-attribute objective function. The five CFAM

outputs used are: the time period when the scenario was complete, campaign completion (yes or no), phase of campaign the scenario advanced to, total number of aircraft lost, and remaining number of targets in the current campaign phase. CFAM produces the outputs when either of two conditions occurs: the campaign completes, or seven time periods have elapsed. Each output is given a weight based on decision maker emphasis on the measure and the resulting objective function value is used as a composite measure of candidate force structure value.

CFAM Setup

Three notional scenarios used to evaluate the proposed multi-scenario optimization methodology are based on the unclassified databases found in the CFAM99 training disk (CFAM99, 1999). The training data was modified to create three theater scenarios. A total of 3,537 targets are divided between the three scenarios. A listing by target class is presented in Table 4. A more detailed listing of the target distribution is located in Appendix 2 where scenario targets are enumerated by type and in Appendix 3 where scenario targets are enumerated by target class.

Table 4. Scenario Target Distribution by Target Class

		Target Entities		
Class ID	**Target Class**	**Theater 1**	**Theater 2**	**Theater 3**
1	Defeat Close Forces	313	48	280
2	Defeat 2nd Echelon Forces	558	24	546
3	Defeat Naval Forces	20	1	22
4	Reduce Sortie Capacity	252	336	288
5	Degrade Air Defenses	51	111	98
6	Degrade Air Control	4	12	12
7	Destroy Weapons of Mass Destruction	6	14	10
8	Degrade Economic/Military Capacity	133	147	106
9	Destroy Leaderships Sites	4	3	3
10	Destroy Lines of Communication	46	31	48
	Total Target Entities	**1387**	**727**	**1413**

The scenario duration is set for seven days in each of the three scenarios. Since the scenarios are so short, CFAM is restricted to utilize the aircraft and weapons in place at the beginning of the campaign. The weapons inventory available for the scenarios is listed in Appendix 4.

Of the 19 aircraft types in the CFAM training database, only five are considered for employment in the notional scenarios. In order to enhance the distinction between aircraft types, the selected aircraft's surge rate, minimum altitude limit, and minimum estimated kills per sortie are modified from the database baseline. The parameters of both the selected types (highlighted) and the remaining baseline aircraft are shown in Table 5.

Table 5. Candidate Aircraft Types and Characteristics

ID	Description	Sortie Surge Rate	Min Alt (ft)	Min EKS
1	Aircraft 1	2	9999	0.005
2	Aircraft 2	2	9999	0.005
3	Aircraft 3	2	9999	0.005
4	Aircraft 4	2	9999	0.005
5	Aircraft 5	2	9999	0.005
6	Aircraft 6	2	9999	0.005
7	Aircraft 7	2	9999	0.005
8	**Aircraft 8**	**2.5**	**1000**	**0.02**
9	**Aircraft 9**	**2.4**	**600**	**0.05**
10	**Aircraft 10**	**1.6**	**600**	**0.04**
11	Aircraft 11	2	9999	0.005
12	Aircraft 12	2	9999	0.005
13	Aircraft 13	2	9999	0.005
14	Aircraft 14	2	9999	0.005
15	Aircraft 15	2	9999	0.005
16	Aircraft 16	2	9999	0.005
17	Aircraft 17	2	9999	0.005
18	**Aircraft 18**	**0.3**	**9999**	**0.005**
19	**Aircraft 19**	**2**	**600**	**0.01**

Multi-Scenario Batch File

CFAM is the Air Force's current LP model used to size a force structure to respond to a single theater scenario. We use CFAM to examine how a single force responds to multi-scenario situations. The key factor that allows multiple runs is the main CFAM input file, gams_in.txt. By using a common time frame, weapon, and aircraft sets in each scenario, the gams_in.txt input file for the LP solver is generated once per scenario. In order to change between force structures, a small portion of this file is modified to reflect a change in the number of aircraft per aircraft type. This research, utilized a notional multi-scenario consisting of three different AEF scenarios. An aircraft and munition dataset is generated to include all the strike aircraft and munition types available for an AEF assignment to create the gams_in.txt file. Mission data files for each scenario are then generated to reflect each scenario's targets and targeting priorities. The force structure file specified by GENESIS is used to change the aircraft numbers in the gams_in.txt file. A multi-scenario batch file (Appendix 5) links this common force structure file to each scenario's specific mission data (including that scenario's target sets and classes), weather profile, and available flight profiles, and submits this group to the CFAM program. The batch file then links this force structure to the next scenario's specific mission data. The process continues until three CFAM runs are conducted, one for each scenario (Figure 4).

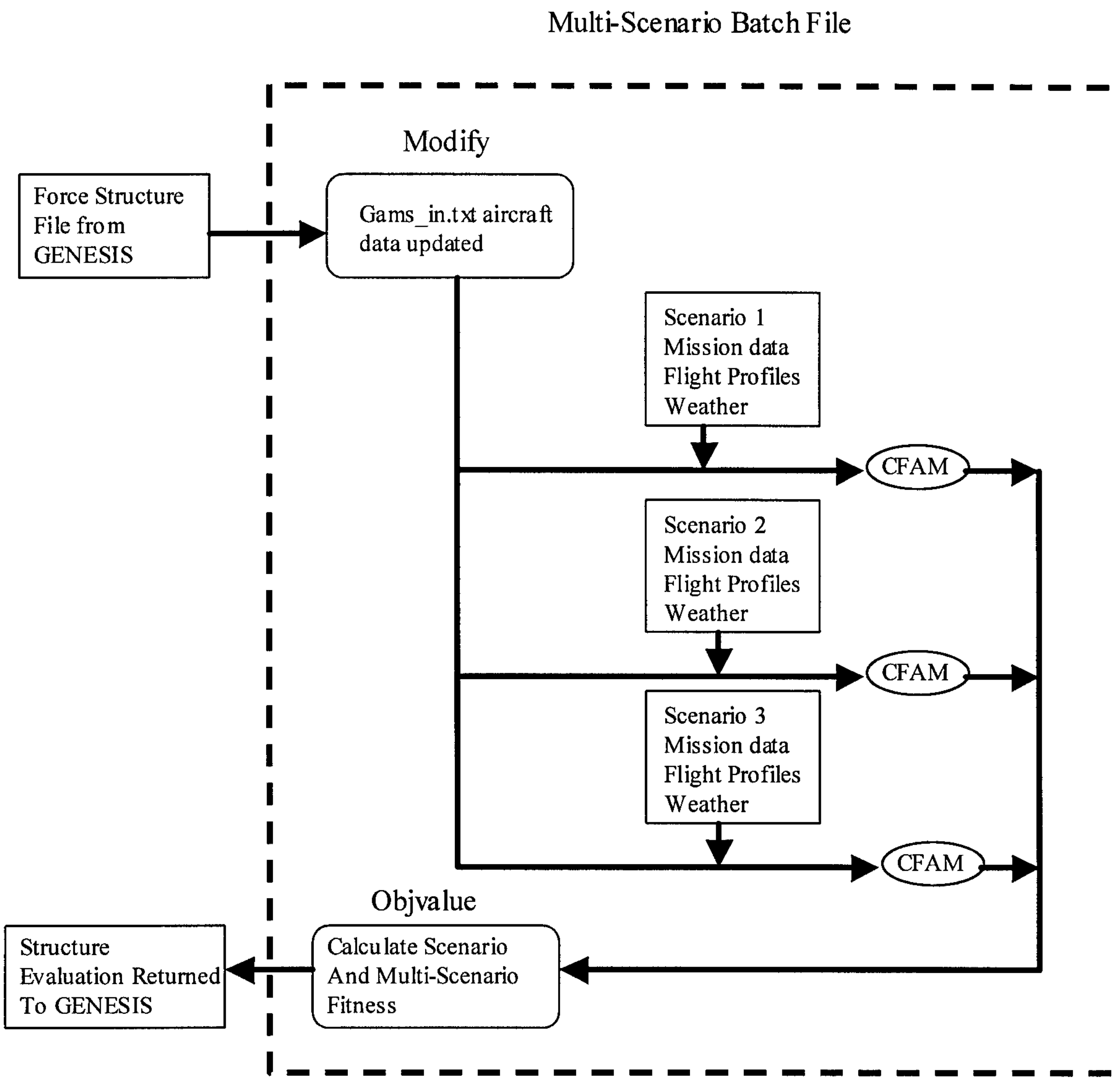

Figure 4. Multi-Scenario Batch File Process Flow

QUICK STRIKE CFAM Variant

The QUICK STRIKE (QS) version of CFAM is used to obtain the parameters needed to calculate the candidate force structure's fitness value. The QS variant solves the munition optimization problem with the goal of minimizing the time required to meet campaign phase goals. The combat campaign in each of the three scenarios consists of four phases: 1) suppression of enemy air defense (SEAD), 2) halting enemy

advancement (HALT), 3) attrition of enemy forces (ATTRIT), and 4) the counter offensive. In order for the campaign to advance to the next phase, certain goals have to be met. The phase goals shown in Table 6 are based on destroying a certain percentage of enemy targets divided among a set of target classes.

QS does not require all of a campaign's phase goals to be satisfied before advancement to the next phase. Switches exist to determine which goals must be satisfied. The switch settings used for this study are listed in Table 7.

QS is defined (Rummer, 1997:2) as, "...a time-myopic model, which optimizes over individual time periods and passes information on to subsequent time periods." In the notional case demonstrated by this thesis, a time period is defined as one day and seven time periods are considered for each scenario.

Table 6. Campaign Phase Goals

Target Class	Phase	Goals Theater 1	Theater 2	Theater 3	Penalty
Defeat Close Forces	1	0.2	0.3	0.4	128
	2	0.6	0.5	0.6	64
	3	0.85	0.8	0.85	64
	4	0.95	0.95	0.95	32
Defeat 2nd Echelon Forces	1	0.2	0.2	0.4	128
	2	0.6	0.4	0.6	64
	3	0.85	0.85	0.85	64
	4	0.95	0.95	0.95	32
Defeat Naval Forces	1	0.3	0.3	0.4	128
	2	0.6	0.6	0.6	64
	3	0.85	0.8	0.85	64
	4	0.95	0.95	0.95	32
Reduce Sortie Capacity	1	0.4	0.4	0.4	128
	2	0.6	0.6	0.6	64
	3	0.85	0.85	0.85	64
	4	0.95	0.95	0.95	32
Degrade Air Defenses	1	0.8	0.8	0.4	128
	2	0.85	0.85	0.6	64
	3	0.9	0.9	0.85	64
	4	0.95	0.95	0.95	32
Degrade Air Control	1	0.6	0.6	0.4	128
	2	0.75	0.75	0.6	64
	3	0.85	0.85	0.85	64
	4	0.95	0.95	0.95	32
Destroy Weapons of Mass Destruction	1	0.2	0.3	0.4	128
	2	0.4	0.5	0.6	64
	3	0.6	0.7	0.85	64
	4	0.95	0.95	0.95	32
Destroy Economic/Military Capacity	1	0.05	0.2	0.4	128
	2	0.1	0.4	0.6	64
	3	0.4	0.8	0.85	64
	4	0.85	0.95	0.95	32
Destroy Leadership Sites	1	0.5	0.5	0.4	128
	2	0.75	0.75	0.6	64
	3	0.85	0.85	0.85	64
	4	0.95	0.95	0.95	32
Destroy Lines of Communication	1	0.4	0.4	0.4	128
	2	0.6	0.6	0.6	64
	3	0.85	0.85	0.85	64
	4	0.95	0.95	0.95	32

Table 7. Campaign Phase Switch Settings

	Theater1	Switch (Y/N)			
Class ID	**Target Class**	**Phase1**	**Phase2**	**Phase3**	**Phase4**
1	Defeat Close Forces	Y	Y		Y
2	Defeat 2nd Echelon Forces	Y	Y	Y	Y
3	Defeat Naval Forces		Y	Y	Y
4	Reduce Sortie Capacity	Y		Y	Y
5	Degrade Air Defenses	Y	Y	Y	Y
6	Degrade Air Control	Y	Y	Y	Y
7	Destroy Weapons of Mass Destruction				Y
8	Degrade Economic/Military Capacity				Y
9	Destroy Leaderships Sites			Y	Y
10	Destroy Lines of Communication	Y	Y	Y	Y

	Theater2	Switch (Y/N)			
Class ID	**Target Class**	**Phase1**	**Phase2**	**Phase3**	**Phase4**
1	Defeat Close Forces		Y		Y
2	Defeat 2nd Echelon Forces		Y	Y	Y
3	Defeat Naval Forces		Y	Y	Y
4	Reduce Sortie Capacity	Y	Y		Y
5	Degrade Air Defenses	Y	Y	Y	Y
6	Degrade Air Control	Y	Y	Y	Y
7	Destroy Weapons of Mass Destruction		Y		Y
8	Degrade Economic/Military Capacity				Y
9	Destroy Leaderships Sites			Y	Y
10	Destroy Lines of Communication	Y	Y	Y	Y

	Theater3	Switch (Y/N)			
Class ID	**Target Class**	**Phase1**	**Phase2**	**Phase3**	**Phase4**
1	Defeat Close Forces	Y	Y		Y
2	Defeat 2nd Echelon Forces	Y	Y	Y	Y
3	Defeat Naval Forces		Y	Y	Y
4	Reduce Sortie Capacity	Y			Y
5	Degrade Air Defenses	Y	Y	Y	Y
6	Degrade Air Control	Y	Y	Y	Y
7	Destroy Weapons of Mass Destruction				Y
8	Degrade Economic/Military Capacity				Y
9	Destroy Leaderships Sites			Y	Y
10	Destroy Lines of Communication	Y	Y	Y	Y

Selection of Fitness Function

In order to compute an individual force structure's fitness value, a scenario objective function is created based on five CFAM performance measures (recorded in the *acc2* output file). The measures are: time period ended, campaign completed, advanced to phase, total aircraft lost, and number of targets remaining in the current phase. The objective function created for each scenario i is as follows:

$$O_i = -w_{1_i} D_0 + w_{2_i} D_1 + w_{3_i} D_2 - w_{4_i} D_3 - w_{5_i} D_4 - w_{6_i} Atotal \qquad (6)$$

where

w_{1_i} through w_{6_i} are parameter weights defined by the decision maker

D_0 = *time period when campaign ended (ranging from 1 to 7),*

D_1 =*campaign completed (0 for no, 1 for yes),*

D_2 = *current phase when campaign ended (ranging from 1 to 4),*

D_3 = *total aircraft lost,*

D_4 = *targets remaining for current phase,*

Atotal = *the total number of aircraft in the force structure.*

The parameter weights could be changed for each scenario but the same weights are used here. Primary emphasis is given to completing the campaign. A bonus is applied for every campaign phase completed and penalties are imposed on parameters D_0, D_3, D_4, and *Atotal* to encourage selection of the smallest force structures that could complete the mission in the shortest time, with the fewest losses, and the fewest remaining unstruck enemy targets. The fitness function value for force structure v_j is calculated as:

$$v_j = \sum_{i=1}^{i} P_i O_i \qquad (7)$$

where i is the scenario number, j is the number of the force structure in the candidate population, and P_i is the probability of scenario i occurring. For the duration of the demonstration, the following parameter weights and probability of occurrence are used:

$w_{1_i} = 50, w_{2_i} = 10000, w_{3_i} = 125, w_{4_i} = 50, w_{5_i} = 50, w_{6_i} = 50,$

and $P_i = 1/3$ for $i = 1, 2, 3$.

Visual Basic Components

Modification of the gams_in.txt file and extraction of the objective function parameters D_0 through D_4 require two visual basic codes: *Modify* and *Objvalue* (Appendix 3). The *Modify* code takes the candidate force structure from the GA module and modifies the aircraft numbers accordingly in the gams_in.txt file. The *Objvalue* code reads in the fitness function parameters from each CFAM run output, calculates each scenario's fitness value, the total force structure fitness value, and returns the total fitness value to GA module.

IV. Data Description and Analysis

Data History

All experiments were run on a high-end desktop computer with two gigabytes of random access memory and running under Windows NT 4.0 with dual 550 MHz Pentium III processors. The notional scenarios were constructed using CFAM version 2.5 and evaluated using GAMS 2.5 linked with the CPLEX Linear Optimizer version 6.5.2. The GA controlling the force structure was GENESIS version 5.0 complied using Borland C++ version 4.52. Runtimes for evaluating a single force structure over three scenarios averaged 16 minutes apiece. Total continuous runtime to complete the three experiment, 942 trial case (Table2) in GENESIS was approximately 11.5 days.

Experimental Output

A total of 942 force structures were evaluated in three, 12-generation GENESIS experiments. The data obtained from these 942 structures are listed in Appendix 7. A portion of this list, the 15 best force structures found, is shown in Table 8. Take note of the small disparity between these structures. One can consider any of these structures as a likely candidate for a robust AEF unit if other considerations are brought to bear. An example of one such consideration is the cost of supporting the selected unit's aircraft in the field. Currently, the lowest level of organic maintenance support for aircraft is at the squadron level. Squadrons are structured to support a certain number of aircraft, typically 18 or 24 for a fighter squadron. It quickly becomes cost prohibitive if only a portion of a squadron is assigned and deploys as part of AEF. A study conducted by Morris, *et al.* found that, "USAF squadrons today...are not organized, trained, nor

equipped to conduct multiple concurrent operations from two or more deployed locations." Split operations require more support equipment and maintenance personnel than if the squadron remained as single unit (Morris and others, 1999:6). To avoid wasting scarce resources, use an alternate structure that most nearly follows the most cost efficient formula of supporting the member aircraft. This alternative may be nearly as effective operationally as its predecessor but be more logistically efficient; and logistical efficiency may lead to further operational benefit. This ability to identify alternative "best" solutions using the research methodology provides a certain robust quality to a list of robust structures.

Table 8. Top 15 Force Structures Found to Date

		Number of Aircraft by Type					Fitness Values			
Rank	Trial	Acft 1	Acft 2	Acft 3	Acft 4	Acft 5	Scenario1	Scenario2	Scenario3	Total
1	181	15	4	0	56	53	3708.50	3662.50	3672.00	3681.00
2	869	18	2	5	42	63	3610.50	3565.00	3577.00	3584.17
3	258	9	18	1	55	47	3589.50	3559.00	3575.00	3574.50
4	250	24	4	0	55	47	3593.00	3558.00	3571.00	3574.00
5	214	9	15	1	58	47	3591.50	3561.00	3565.50	3572.67
6	855	16	7	5	42	61	3557.50	3517.50	3534.50	3536.50
7	241	16	4	0	56	55	3560.00	3516.00	3530.50	3535.50
8	288	21	4	1	56	49	3549.00	3510.00	3524.00	3527.67
9	896	16	15	4	36	60	3543.00	3508.50	3526.00	3525.83
10	230	24	4	1	55	47	3542.50	3508.00	3526.00	3525.50
11	232	9	19	1	55	47	3542.50	3508.50	3524.50	3525.17
12	884	16	7	4	45	60	3509.00	3466.50	3520.00	3498.50
13	863	16	7	4	45	61	3461.00	3417.00	3471.00	3449.67
14	900	16	7	5	44	61	3459.50	3417.00	3470.50	3449.00
15	872	31	2	5	44	51	3431.00	3402.00	3459.50	3430.83

Table 8 also illustrates a concern with this approach. The GA heavily favors Aircraft 4 and Aircraft 5 while barely utilizing Aircraft 3. A practical force structure may require a more balanced force. A good question for further research is how to encourage the GA to find balanced, robust solutions and how to force the GA to examine those regions of the solution space containing balanced, robust force structures.

A word of caution is required when viewing the information in Table 8. The table displays the top 15 force structures found to date. The structures are the best found after

a search of only a fraction of the total solution space. With each of the five aircraft types in the force structure allowed to take on one of a possible 64 values, the number of possible structures to consider is over a billion. In fact, there are 64^5 or 1,073,741,824 candidate structures. As a percentage of the solution space searched this is only:

$$\frac{942}{1{,}073{,}741{,}824} * 100\% = 0.00008773\% \tag{7}$$

Our problem is a multi-criteria optimization problem across multiple scenarios. The multi-scenario solution space is likely highly non-linear. Figure 5 is a two-dimensional slice of the multi-scenario space focused just on Aircraft 1 and Aircraft 2 levels. Despite the sparcity of solution space coverage, one can start to appreciate the non-linearity of the space. This empirical evidence of our conjecture regarding the multi-scenario solution space supports the use of a meta-heuristic such as a GA. Slices comparing other combinations of aircraft levels exhibited similar ruggedness of the solution space.

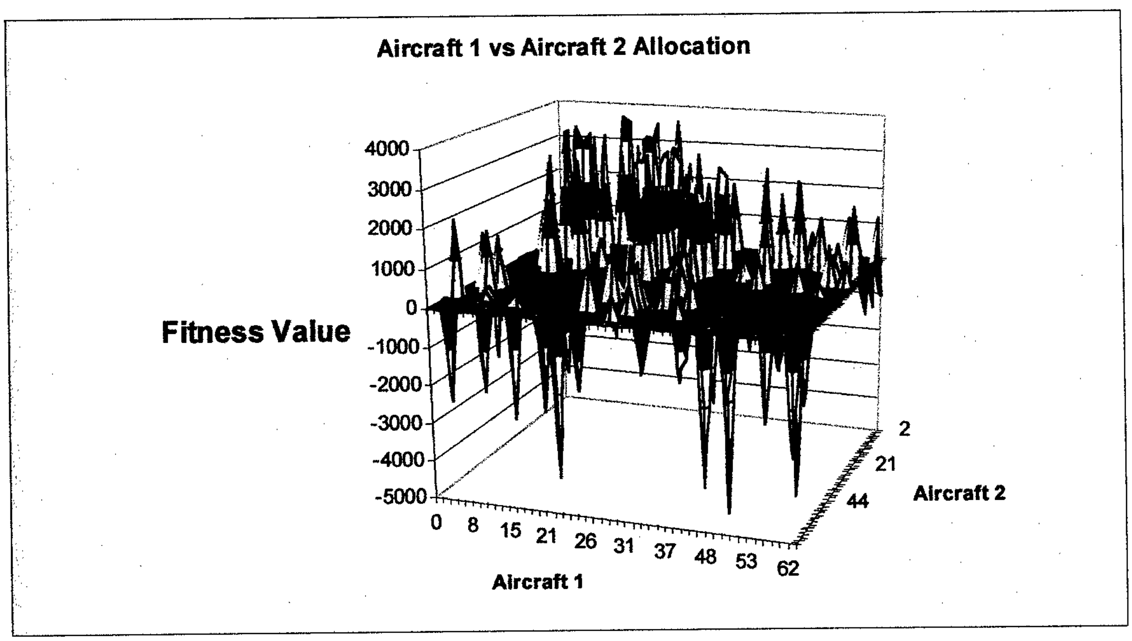

Figure 5. Fitness Comparison of Aircraft 1 vs. Aircraft 2 Allocation

GA Performance Analysis

In general, a meta-heuristic's performance is evaluated based either on solution quality or solution speed. Unfortunately neither measure is available in the current case. We have no way to find the optimal solution, short of complete enumeration, which would take far too long. Instead, we use three typical GA measures of performance. These measures are described by Reeves (1995:164) as on-line, off-line, and best-so-far. These measures are generally depicted graphically. The data are provided in Table 9 and plotted in Figure 6, Figure 7, and Figure 8 for the three GA experiments run. The three GA measures are quite useful for assessing GA performance. On-line performance is equal to the average of all evaluations during an experiment. Off-line performance is equal to the average of the current best solutions, and best-so-far is simply the best solution found so far in the experiment. Best-so-far is the primary measure of performance.

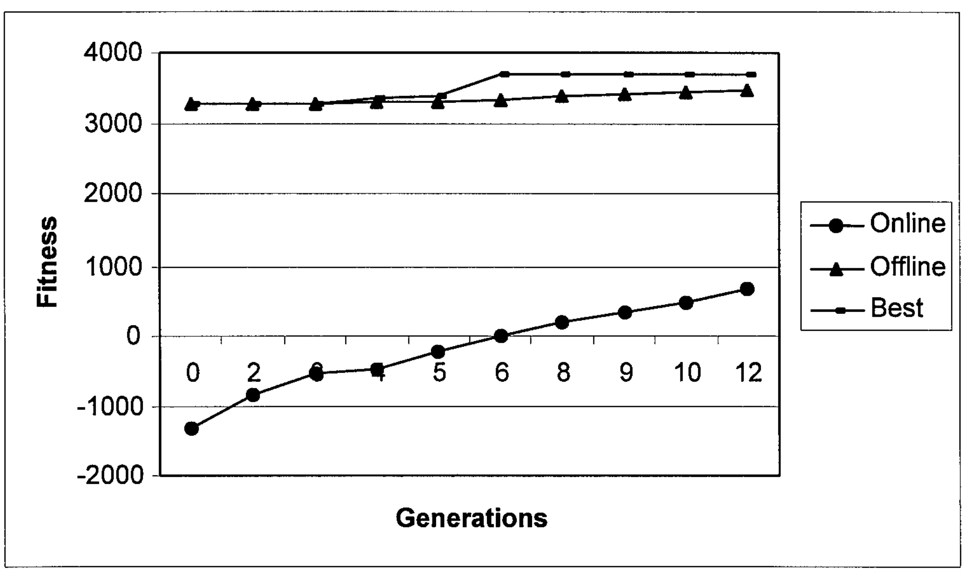

Figure 6. GA Performance for Experiment 1

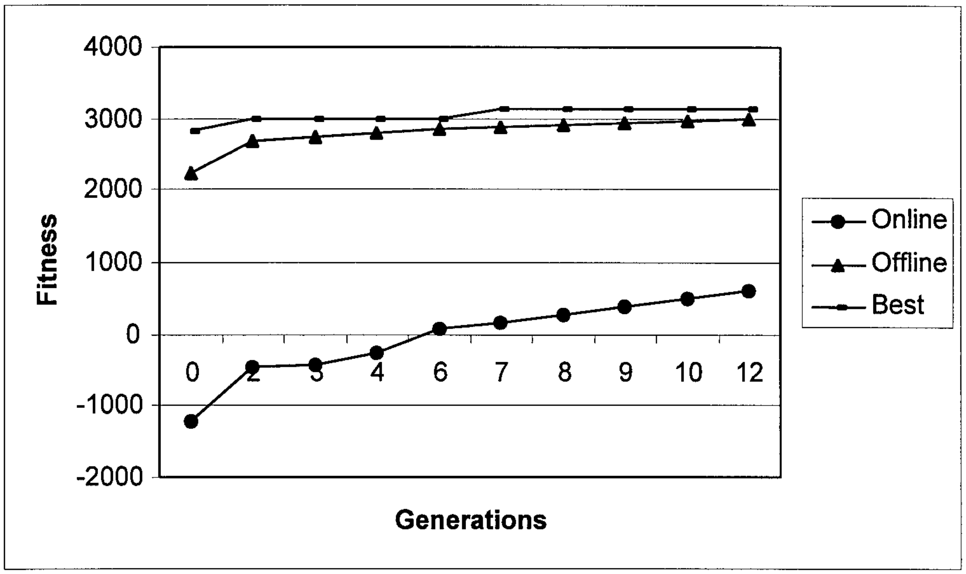

Figure 7. GA Performance for Experiment 2

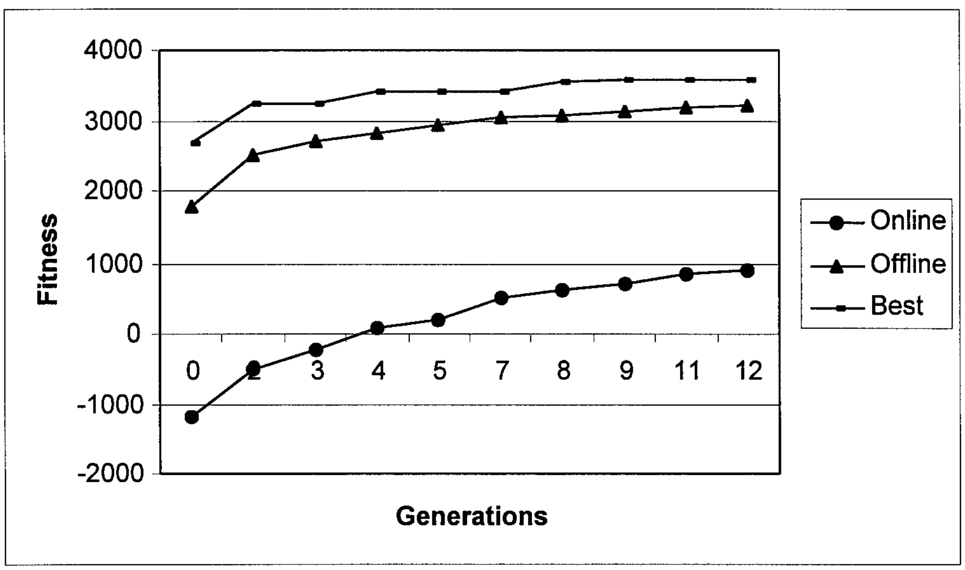

Figure 8. GA Performance for Experiment 3

Table 9. GA Performance Data

Experiment 1								
Generation	Trials	Lost	Conv	Bias	Online	Offline	Best	Average
0	30	0	0	0.551	-1331	3278	3278	-1331
2	76	0	0	0.611	-840	3278	3278	-106
3	103	0	0	0.639	-541	3278	3278	323
4	131	0	0	0.64	-468	3295	3358	-53
5	155	0	1	0.671	-225	3307	3371	852
6	182	1	1	0.694	-9	3319	3681	1229
8	227	2	2	0.716	187	3391	3681	1481
9	249	2	2	0.721	340	3417	3681	1966
10	270	2	3	0.718	469	3437	3681	2047
12	315	3	4	0.746	689	3472	3681	2136

Experiment 2								
Generation	Trials	Lost	Conv	Bias	Online	Offline	Best	Average
0	30	0	0	0.569	-1218	2229	2829	-1218
2	78	0	0	0.626	-465	2672	3004	480
3	96	0	0	0.647	-434	2734	3004	354
4	120	0	1	0.662	-272	2788	3004	710
6	169	1	1	0.682	80	2851	3004	1003
7	195	1	1	0.696	161	2884	3129	814
8	222	1	1	0.688	267	2914	3129	1167
9	248	1	1	0.688	384	2937	3129	1455
10	272	1	3	0.693	491	2954	3129	1756
12	320	1	1	0.697	617	2980	3129	1308

Experiment 3								
Generation	Trials	Lost	Conv	Bias	Online	Offline	Best	Average
0	30	0	0	0.576	-1182	1786	2664	-1182
2	74	0	0	0.629	-500	2517	3247	504
3	98	0	0	0.642	-225	2696	3247	780
4	125	0	0	0.669	71	2826	3399	1161
5	150	0	0	0.697	208	2922	3399	954
7	197	1	2	0.75	495	3036	3399	1674
8	223	2	2	0.769	607	3080	3537	1552
9	248	2	2	0.783	696	3129	3584	1681
11	287	1	3	0.783	840	3191	3584	2009
12	307	1	3	0.777	913	3217	3584	2063

All three Figures 6, 7, and 8 show the best-so-far curve leveling off. However, the on-line performance curves are still increasing. This warrants further investigation. The GA population may be converging but, given the concerns about sparse solution

space coverage and unbalanced force structures, may be converging to some local optimum. Many more generations are required before coming to any firm conclusions.

V. Findings and Conclusions

Findings

By combining elements of Robust Optimization (1) and Multiple Criteria Decision Making (2), the research methodology has demonstrated that it can search a large, complex, and non-convex solution space and find robust AEF strike force structures. In section IV we found that the "best" robust solution may not always be the preferred choice but that the methodology can provide a range of robust solutions that can be traded off in deference to other factors.

The methodology has the ability to be tailored as required by the decision maker. Different levels of available aircraft can be modeled by restricting the range assigned to the aircraft gene in the GENESIS GA. Changing the phase goals in CFAM allows selection of robust force structures across a range of scenarios with different victory conditions in each scenario. For example, in one scenario, campaign success may hinge on destroying all the enemy's command and control bunkers. In another scenario, campaign success may hinge on destroying all the enemy's aircraft carriers. Differing decision maker objectives and concerns can also be addressed by changing the weights in the scenario fitness objective function, (6). In the research example, the weights were set to make campaign success the primary objective in each scenario. If the decision maker wanted to make not losing aircraft in one scenario of equal importance to campaign success, then all he had to do was change two weights in that scenario's objective function.

Utilizing the CFAM model to perform the evaluation of a structure's fitness level for the GENESIS GA made good use of an existing model but as with any complex

model, requires significant processing times. Our notional scenarios required 16 minutes per multi-scenario run. Realistic scenarios will very likely require longer run times. Further, realistic scenarios will definitely examine more than five aircraft levels. Longer run times, longer chromosome lengths (to accommodate more decision variables) equate to many more model evaluations by the GA.

Conclusions and Areas for Further Research

The research methodology appears to work on the notional level but needs further refinement before it can confidently be applied to larger problems. The restrictions imposed by the long computer runtimes severely limited exercise and exploration of the methodology. However, the experience still gives rise to some areas of further exploration.

Existing models, existing scenarios, and off-the-shelf GA code appears to be the correct approach. For this research, various work-arounds were necessary to update input files and prepare CFAM runs. A realistic assessment using our approach will require specialized CFAM input files to facilitate CFAM evaluations.

Realistic scenarios (*i.e.* classified databases) are the true test of any new military analysis methodology. A future effort should employ this methodology using real scenarios, examining more decision variables, and examining both aircraft and munitions. Once the realistic scenarios are in hand, further research should be addressed to the utility of seeding the GA with high-quality solutions found from another heuristic or a design of experiment.

Empirical experience strongly suggests parameter tuning is necessary to obtain quality results from a GA. Further research should address the appropriate combination of parameter values (or range of values) to solve multi-scenario problems. Further, since aircraft and munitions decision variables are bounded variables, one might examine using

a design of experiments approach to generate an initial population. Such an approach may likely provide adequate scenario space coverage and provide a greater variety of feasible force structures.

A final area of research is to examine the analytical implications of robust, multi-scenario optimization. For instance, how might one approach sensitivity analysis? How should the various weights be defined for the fitness function? Which model measures are the most influential when searching the multi-scenario space? Such questions require additional research and thought to adequately answer.

Making force structure decisions to meet an uncertain future in now a fact of life for the military services. Procurement of aircraft and munitions must be driven by probable need, justified as meeting that need, and demonstrated as being in the best interest of meeting the foreseeable needs of both the military service and the nation. The numerous diverse conflicts the United States has been involved in the last ten years have shown just how unpredictable the foreseeable future can be, how badly a new planning tool is needed, and why further research into this topic is required.

Appendix 1: GENESIS Evaluation Function

```
/*              File:  eval.c
*/
#include <string.h>
#include <stdlib.h>
#include <stdio.h>
#include <fcntl.h>
#include <io.h>
/*
        CFAM Multi-Scenario Run Evaluation Function for GENESIS

        Written By:  Greg McIntyre
                     Ray Hill
                     Barry Bennett

        Language:  C/C++

        Sources used:   C/C++ manuals

*/
double eval(str, length, vect, genes)
char str[];                   /* string representation */
int length;                   /* length of bit string */
double vect[];                /* floating point representation */
int genes;                    /* number of elements in vect   */
{
    FILE *Instream, *Outstream, *fopen();
    float sumf;
    double sum;

/*
            Open the file and print the phenotypes only.
            Close file once all data written.
            This section prints out the candidate structure to a file named
            "numacft.txt".
*/
    Outstream = fopen("numacft.txt", "w+");
    fprintf(Outstream, "%5.0f%5.0f%5.0f%5.0f%5.0f \n", vect[0], vect[1],
    vect[2], vect[3], vect[4]);
    fclose(Outstream);
    printf("%8.3f%8.3f%8.3f%8.3f%8.3f \n", vect[0], vect[1],
    vect[2], vect[3], vect[4]);
/*
```

```
		Call the CFAM via DOS command line call
*/
	system("master");
/*
		Open the file created after the CFAM runs.
		File contains value of the evaluation function.

*/
	Instream = fopen("evalue.txt", "r");
	fscanf(Instream, "%10f", &sumf);
	sum = sumf;
	fclose(Instream);

	return(sum);
}
```

Appendix 2: Theater Targets By Type

Target ID	Elements	Description	Number of Targets by Type Theater 1	Theater 2	Theater 3
1	1	Ferry	1	2	1
2	2	Railroad Yard Choke Point	3	1	2
3	12	Truck Column	2	1	1
4	4	MLRS in Position	2	0	2
5	1	Air to Surface Missile in Travel	1	3	2
6	10	Open Storage, Inert Supplies	1	2	1
7	10	Open Storage, Munitions	2	4	1
8	24	Truck Park	1	0	1
9	16	Bridge Type 1	2	1	2
10	10	Bldg Storage	3	2	1
11	6	Iron/Steel Plant (Blast Furnaces)	2	1	2
12	1	Bldg w/Machine Tools	6	3	4
13	1	Bldg. Manufacturing/ Assembly	3	2	3
14	4	POL, Airfield POL Storage, small	1	3	2
15	1	Bunker, Arch	2	4	8
16	1	Bunker, Aircraft	6	18	12
17	30	POL, Airfield POL Storage	2	3	2
18	1	Runway-A/C Highway Strip	3	6	2
19	1	Runway-Earth Hard Soil	0	0	1
20	1	Runway-Asphalt	2	4	3
21	1	Taxiway-Concrete/Asphalt	2	4	3
22	1	Acft Bunker, Double Shell	10	15	8
23	8	Acft Bunker, Large	2	4	5
24	2	Acft Hanger, Steel	9	20	11
25	1	Taxiway Bridge	0	1	0
26	1	Bridge, Pontoon	0	1	2
27	1	Bridge, Highway	4	5	5
28	1	Bridge, Dual Purpose	3	5	4
29	14	Port Facilities, Cranes	1	0	1
30	1	Marine Facility Tunnel Adit	1	0	2
31	1	Port Facility Transverser	2	1	2
32	6	Transformer Yard Large	2	1	2
33	12	Transformer Yard Small	1	2	1
34	3	POL Pump Station	2	1	2
35	6	POL Storage Tanks Above Ground	2	1	2
36	3	POL Refineries Rupture Kill	1	2	1
37	1	Ship, Carrier	0	0	1
38	1	Ship, Cruiser	3	0	3
39	3	Newer Tank Platoon	20	1	10
40	3	Modern Tank Platoon	5	1	3
41	1	Radar in Open, M-Kill	2	5	3
42	4	SAM Missile System	2	5	5

Target ID	Elements	Description	Number of Targets by Type Theater 1	Theater 2	Theater 3
43	1	Radar, SAM site Msn Kill	5	10	4
44	3	SAM Telars	2	6	6
45	1	Bunker, Command & Control	2	2	3
46	1	Bunker, Generic Sector OPS Center	1	2	3
47	2	Radar, Revetted EW/GCI	1	4	3
48	1	Radar, EW/GCI Site	1	2	3
49	28	Aircraft, Fighter Newer	1	2	3
50	30	Aircraft, Bomber	2	1	1
51	10	Acft, Helicopter	2	1	0
52	7	Acft, Fighter Old	3	2	1
53	420	Personnel, Bivovac/Assembly	1	0	1
54	200	Personnel, Prone	1	0	1
55	31	Modern Tank Column	1	0	1
56	9	SAM, Short Range Fire Unit	2	4	4
57	6	ARTY, SPG in Position K-Kil	3	6	4
58	6	ARTY, XX-mm Twed Field Gun/How	3	2	3
59	31	APC Battalion (BMPs)	1	0	1
60	3	APC Platoon (BMPs)	4	2	3
61	10	APC Column (BMP)	1	0	1
62	1	Radar SAM Short	4	8	6
63	1	Radar, Sam Medium	6	12	8
64	1	SSM, Missile site, one missile in tel	5	11	8
65	5	Bldg. RIC/HSF with 10-25 T crane	1	2	2
66	1	Bldg. Nuclear Research Facility	2	1	2
67	1	Nuclear WPNS Support Bunker	0	0	0
68	1	Nuclear WPNS Support Bunker	0	0	0
69	1	Bunker, Command & Control	3	2	2
70	1	Bunker, Ministry of Defense	1	1	1
		Total Target Entities	1387	727	1413

Appendix 3: Theater Targets by Target Class

		Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Target Class:	**Defeat 2nd Echelon Forces**				
Included Tgts:	APC Battalion (BMPs)	31	1	0	1
	APC Column (BMPs)	10	1	0	1
	ARTY, xx-mm towed field gun/howitzer	6	3	2	3
	Modern Tank Column	31	1	0	1
	Personnel Bivouac/Assembly	420	1	0	1
	Truck Column	12	2	1	1
	Truck Park	24	1	0	1
	Total Target Entities		558	24	546

		Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Target Class:	**Defeat Close Forces**				
Included Tgts:	APC Platoon (BMPs)	3	4	2	3
	ARTY, SPG in position, K-kill	6	3	6	4
	MLRS in Position	4	2	0	2
	Modern Tank Platoon	3	5	1	3
	Newer Tank Platoon	3	20	1	10
	Personnel Prone	200	1	0	1
	Total Target Entities		313	48	280

		Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Target Class:	**Defeat Naval Forces**				
Included Tgts:	Marine Facility Tunnel ADIT	1	1	0	2
	Port Facilities Cranes	14	1	0	1
	Port Facility Transverser	1	2	1	2
	Ship, Carrier	1	0	0	1
	Ship, Crusier	1	3	0	3
	Total Target Entities		20	1	22

		Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Target Class:	**Degrade Air Control**				
Included Tgts:	Bunker, Generic Sector Ops Center	1	1	2	3
	Radar, EW/GCI Site	1	1	2	3
	Radar, Revetted EW/GCI	2	1	4	3
	Total Target Entities		4	12	12

Target Class:	Degrade Air Defenses	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Bunker, Command & Control	1	2	2	3
	Radar, SAM short	1	4	8	6
	Radar in open, M-kill	1	2	5	3
	Radar, SAM site MSN kill	1	5	10	4
	Radar, SAM medium	1	6	12	8
	SAM Missile System	4	2	5	5
	SAM Telars	3	2	6	6
	SAM, short range fire unit	9	2	4	4
	Total Target Entities		51	111	98

Target Class:	Degrade Economic/Military Capacity	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Bldg, Storage	10	3	2	1
	Bldg, Manufacturing/Assembly	1	3	2	3
	Bldg, Nuclear Research Facility	1	2	1	2
	Bldg, RIC/HSF with 10-25 ton crane	5	1	2	2
	Bldg with machine tools	1	6	3	4
	Iron/Steel Plant (blast furnaces)	6	2	1	2
	Open Storage, Inert Supplies	10	1	2	1
	Open Storage, Munitions	10	2	4	1
	POL Pump Station	3	2	1	2
	POL Refineries, Rupture Kill	3	1	2	1
	POL Storage Tanks, above ground	6	2	1	2
	Transformer Yard, Large	6	2	1	2
	Transformer Yard, Small	12	1	2	1
	Total Target Entities		133	147	106

Target Class:	Destroy Leaderships Sites	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Bunker, Command & Control	1	3	2	2
	Bunker, Ministry of Defense	1	1	1	1
	Total Target Entities		4	3	3

Target Class:	Destroy Lines of Communication	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Ferry	1	1	2	1
	Bridge Type 1	16	2	1	2
	Bridge, Dual Purpose	1	3	5	4
	Bridge, Highway	1	4	5	5
	Bridge, Pontoon	1	0	1	2
	Railroad Yard Chokepoint	2	3	1	2
	Total Target Entities		46	31	48

Target Class:	Destroy Weapons of Mass Destruction	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Air to Surface Missile in travel mode	1	1	3	2
	Nuclear Wpns Support Bunker, earth covered	1	0	0	0
	Nuclear Weapons Support Bunker, earth covered	1	0	0	0
	SSM, Missile Site, one missile on TEL	1	5	11	8
	Total Target Entities		6	14	10

Target Class:	Reduce Sortie Capacity	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Acft Hanger, Steel	2	9	20	11
	Acft Bunker, Double Shell	1	10	15	8
	Acft Bunker, Large	8	2	4	5
	Aircraft, Helicopters	10	2	1	0
	Aircraft, Bomber	30	2	1	1
	Aircraft, Fighter Newer	28	1	2	3
	Aircraft, Fighter Old	7	3	2	1
	Bunker, Arch	1	2	4	8
	Bunker, Aircraft	1	6	18	12
	POL, Airfield POL Storage, small underground	4	1	3	2
	POL, Airfield POL Storage	30	2	3	2
	Runway - A/C Highway Strip	1	3	6	2
	Runway - Asphalt	1	2	4	3
	Runway - Earth, Hard Soil	1	0	0	1
	Taxiway - Concrete/Asphalt	1	2	4	3
	Taxiway Bridge	1	0	1	0
	Total Target Entities		252	336	288

Appendix 4: Weapons Inventory

ID	Description	Inventory
25	Smart Rock Type 1	50,000
26	Smart Rock Type 2	50,000
27	Smart Rock Type 3	50,000
28	Smart Rock Type 4	50,000
29	Smart Rock Type 5	50,000
31	Smart Rock Type 6	50,000
33	Smart Rock Type 7	50,000
34	Smart Rock Type 8	50,000
35	Smart Rock Type 9	50,000
40	Smart Rock Type 10	50,000
41	Smart Rock Type 11	50,000
42	Smart Rock Type 12	50,000
1	Rock Type 1	10,000
2	Rock Type 2	50,000
3	Rock Type 3	50,000
4	Rock Type 4	50,000
5	Rock Type 5	50,000
6	Rock Type 6	50,000
7	Rock Type 7	10,000
8	Rock Type 8	50,000
9	Rock Type 9	10,000
10	Rock Type 10	50,000
24	Rock Type 11	50,000
47	Powered Rock Type 1	50,000
48	Powered Rock Type 2	50,000
49	Powered Rock Type 3	50,000
50	Powered Rock Type 4	50,000
51	Powered Rock Type 5	10,000
52	Powered Rock Type 6	10,000
53	Powered Rock Type 7	50,000
54	Powered Rock Type 8	50,000
55	Powered Rock Type 9	50,000
56	Powered Rock Type 10	50,000
57	Powered Rock Type 11	10,000
58	Powered Rock Type 12	50,000
59	Powered Rock Type 13	50,000
60	Powered Rock Type 14	50,000
61	Powered Rock Type 15	50,000
62	Powered Rock Type 16	50,000

ID	Description	Inventory
43	GBU-Rock Type 1	50,000
44	GBU-Rock Type 2	50,000
45	GBU-Rock Type 3	50,000
46	GBU-Rock Type 4	50,000
11	GBU-Rock Type 5	50,000
12	GBU-Rock Type 6	50,000
13	GBU-Rock Type 7	50,000
14	GBU-Rock Type 8	50,000
15	GBU-Rock Type 9	50,000
16	GBU-Rock Type 10	50,000
17	GBU-Rock Type 11	50,000
18	GBU-Rock Type 12	50,000
19	GBU-Rock Type 13	50,000
20	GBU-Rock Type 14	50,000
21	GBU-Rock Type 15	50,000
22	GBU-Rock Type 16	50,000
23	GBU-Rock Type 17	50,000
30	GBU-Rock Type 18	50,000
32	GBU-Rock Type 19	50,000
36	GBU-Rock Type 20	50,000
37	GBU-Rock Type 21	50,000
38	GBU-Rock Type 22	50,000
39	GBU-Rock Type 23	50,000

Appendix 5: Batch Files

```
@echo off
rem ***
rem ***        File: master.bat
rem ***
rem **         Multi-Scenario batch File
rem **
rem **         Written by: Barry D. Bennett Jr.
rem **
rem **         Language: DOS
rem **
rem **
rem ********************************
rem ** Change aircraft numbers in datacft module of gams_in.txt
rem ********************************
call modify
rem ********************************
rem **   setup scenario input files and run scenario 1
rem ********************************
copy msndat1.txt msndat.txt
copy profile1.txt profiles.txt
copy profwx1.txt profwx.txt
rem **
rem ** Call scenario 1 batch file
rem **
call t1_batch
rem ** output to -a00
rem ********************************
rem ***   setup scenario input files and run scenario 2
rem ********************************
copy msndat2.txt msndat.txt
copy profile2.txt profiles.txt
copy profwx2.txt profwx.txt
rem **
rem **
rem ** Call scenario 2 batch file
rem **
call t2_batch
rem ** output to -a01
rem ********************************
rem ***  setup scenario input files and run scenario 3
rem ********************************
copy msndat3.txt msndat.txt
copy profile3.txt profiles.txt
```

```
copy profwx3.txt profwx.txt
rem **
rem **
rem ** Call scenario 3 batch file
rem **
call t3_batch
rem ** output to -a02
rem ********************************
rem ***   Collect run data and calculate value function
rem ********************************
call objvalue
rem **
rem **  *END OF Multi-Scenario BATCH RUN
****************************************
exit
```

```
rem ******************************************
rem ***        File: t1_batch.bat
rem ***
rem **         Scenario 1 batch File
rem **
rem **         Written by:  Barry D. Bennett Jr.
rem **
rem **         Language:  DOS
rem **
rem ******************************************
rem **
rem **  Add new force structure info to gams input file
rem **
rem **
copy oneA.txt+newslug.txt+oneB.txt gams_in.txt
rem **
rem **
copy budg00_1.txt budg00.txt
copy budg01_1.txt budg01.txt
copy budg02_1.txt budg02.txt
rem **
cd\cfam99~1\runfiles
rem *************************************
rem ** Conduct the CFAM run
rem ***********************************
gams qstrikeg
rem **
rem ***********************************
rem ** Save the CFAM run output files
rem ***********************************
copy c:\cfam99~1\outfiles\acc2.csv c:\cfam99~1\outfiles\acc2-a00.csv
copy c:\cfam99~1\outfiles\form2.csv c:\cfam99~1\outfiles\form2-a01.csv
copy c:\cfam99~1\outfiles\solvar2.csv c:\cfam99~1\outfiles\solvar2a.csv
copy c:\cfam99~1\outfiles\sum2.csv c:\cfam99~1\outfiles\sum2-a00.csv
copy c:\cfam99~1\outfiles\time2.csv c:\cfam99~1\outfiles\time2-a0.csv
rem **
rem **
cd\cfam99~1\infiles
rem **  *END OF BATCH RUN ******************************************
```

```
rem *******************************************
rem ***         File: t2_batch.bat
rem ***
rem **          Scenario 2 batch File
rem **
rem **          Written by:  Barry D. Bennett Jr.
rem **
rem **          Language:  DOS
rem **
rem *******************************************
rem **
rem **  Add new force structure info to gams input file
rem **
copy twoA.txt+newslug.txt+twoB.txt gams_in.txt
rem **
rem **
copy budg00_2.txt budg00.txt
copy budg01_2.txt budg01.txt
copy budg02_2.txt budg02.txt
rem **
cd\cfam99~1\runfiles
rem ***************************************
rem ** Conduct the CFAM run
rem ************************************
gams qstrikeg
rem **
rem ************************************
rem ** Save the CFAM run output files
rem ************************************
copy c:\cfam99~1\outfiles\acc2.csv c:\cfam99~1\outfiles\acc2-a01.csv
copy c:\cfam99~1\outfiles\form2.csv c:\cfam99~1\outfiles\form2-a1.csv
copy c:\cfam99~1\outfiles\solvar2.csv c:\cfam99~1\outfiles\solvar2b.csv
copy c:\cfam99~1\outfiles\sum2.csv c:\cfam99~1\outfiles\sum2-a01.csv
copy c:\cfam99~1\outfiles\time2.csv c:\cfam99~1\outfiles\time2-a1.csv
rem **
rem **
cd\cfam99~1\infiles
rem **  *END OF BATCH RUN *******************************************
```

```
rem ******************************************
rem ***        File: t3_batch.bat
rem ***
rem **         Scenario 3 batch File
rem **
rem **         Written by:  Barry D. Bennett Jr.
rem **
rem **         Language:  DOS
rem **
rem ******************************************
rem **
rem **
rem **  Add new force structure info to gams input file
rem **
c:
cd\cfam99~1\infiles
copy threeA.txt+newslug.txt+threeB.txt gams_in.txt
rem **
rem **
copy budg00_3.txt budg00.txt
copy budg01_3.txt budg01.txt
copy budg02_3.txt budg02.txt
cd\cfam99~1\runfiles
rem *************************************
rem ** Conduct the CFAM run
rem **********************************
gams qstrikeg
rem **
rem **********************************
rem ** Save the CFAM run output files
rem **********************************
copy c:\cfam99~1\outfiles\acc2.csv c:\cfam99~1\outfiles\acc2-a02.csv
copy c:\cfam99~1\outfiles\form2.csv c:\cfam99~1\outfiles\form2-a02.csv
copy c:\cfam99~1\outfiles\solvar2.csv c:\cfam99~1\outfiles\solvar2c.csv
copy c:\cfam99~1\outfiles\sum2.csv c:\cfam99~1\outfiles\sum2-a02.csv
copy c:\cfam99~1\outfiles\time2.csv c:\cfam99~1\outfiles\time2-a2.csv
rem **
rem **
cd\cfam99~1\infiles
rem **  *END OF BATCH RUN ****************************************
```

Appendix 6: Visual Basic Files

```
' *****************************************
' ***   File: modify.exe
' ***
' **    GAMS input file modification routine.
' **
' **    This program reads in the new candidate force structures provided by the
' **    GENESIS GA and modifies the aircraft numbers in the GAMS input file for the
' **    CFAM runs. CFAM requires that the minimum aircraft number in any aircraft
' **    type be one. To insure this aircraft is not used, a sortie rate of zero is given to that
' **     aircraft.
' **
' **    Written by: Barry D. Bennett Jr.
' **
' **    Language: Visual Basic 6.0
' **
' *****************************************
Private Sub Form_Load()
  Dim txt As String
  Dim Acft() As String
  Dim AcftType As String
  Dim Acft8 As String, Acft9 As String, Acft10 As String, Acft18 As String
  Dim Acft19 As String
  Dim A() As String
  Dim B() As String
  Dim I As Integer
  Dim J As Integer
  Dim X As Integer
  Open "C:\Cfam99~1\Infiles\oldslug.txt" For Input As #1
  Open "C:\Cfam99~1\Infiles\numacft.txt" For Input As #2
  Open "C:\Cfam99~1\Infiles\newslug.txt" For Output As #3
  Open "C:\Cfam99~1\Infiles\tempmod.txt" For Output As #4
' **
' ** Read in the aircraft numbers from the new force structure
' **
  Line Input #2, AcftType
  Acft = Split(SuperTrim(AcftType))
  For k = LBound(Acft) To UBound(Acft)
    If k = 0 Then Acft8 = Acft(k)
    If k = 1 Then Acft9 = Acft(k)
    If k = 2 Then Acft10 = Acft(k)
    If k = 3 Then Acft18 = Acft(k)
    If k = 4 Then Acft19 = Acft(k)
  Next k
```

```
    Print #4, Acft8, Acft9, Acft10, Acft18, Acft19

' ***
' **     Read in aircraft number data table from current section of the GAMS input file.
' **     Modify it to reflect change in aircraft numbers and write the changed lines into a
' **     new file.
' ***

    Do Until EOF(1)
      Line Input #1, txt
      A = Split(SuperTrim(txt))
      B = Split(A(LBound(A)), ".")
      Print #4, txt
      For k = LBound(A) To UBound(A)
        Print #4, "k= ", k, "A(k)=", A(k), "B(k)=", B(k)
      Next k
      If B(2) = "T1" Then
        If B(1) = "8" Then
          If Acft8 = "0" Then
            Print #3, A(0); Tab(19); "1"; Tab(29); "0.0000"
          Else
            Print #3, A(0); Tab(19); Acft8; Tab(29); A(2)
          End If
        ElseIf B(1) = "9" Then
          If Acft9 = "0" Then
            Print #3, A(0); Tab(19); "1"; Tab(29); "0.0000"
          Else
            Print #3, A(0); Tab(19); Acft9; Tab(29); A(2)
          End If
        ElseIf B(1) = "10" Then
          If Acft10 = "0" Then
            Print #3, A(0); Tab(19); "1"; Tab(29); "0.0000"
          Else
            Print #3, A(0); Tab(19); Acft10; Tab(29); A(2)
          End If
        ElseIf B(1) = "18" Then
          If Acft18 = "0" Then
            Print #3, A(0); Tab(19); "1"; Tab(29); "0.0000"
          Else
            Print #3, A(0); Tab(19); Acft18; Tab(29); A(2)
          End If
        ElseIf B(1) = "19" Then
          If Acft19 = "0" Then
            Print #3, A(0); Tab(19); "1"; Tab(29); "0.0000"
          Else
```

```
                Print #3, A(0); Tab(19); Acft19; Tab(29); A(2)
            End If
        Else
            Print #3, A(0); Tab(19); A(1); Tab(29); "0.0000"
        End If
    Else
        Print #3, A(0); Tab(19); A(1); Tab(29); A(2)
    End If

  Loop
  Close #1
  Close #2
  Close #3
  Close #4
  End
End Sub
‘ ***********************************
‘ **
‘ **  Subroutine to reduce the number of blank spaces between words on a line of text to
‘ **  one.
‘ **
‘ ***********************************
 Public Function SuperTrim(TheString As String) As String
  Dim temp As String, DoubleSpaces As String
  DoubleSpaces = Chr(32) & Chr(32)
  temp = Trim(TheString)
  temp = Replace(temp, DoubleSpaces, Chr(32))
  Do Until InStr(temp, DoubleSpaces) = 0
    temp = Replace(temp, DoubleSpaces, Chr(32))
  Loop
  SuperTrim = temp
End Function

‘ *********** End of Modify.exe program *********************
```

```
' *****************************************
' ***   File: objvalue.exe
' ***
' **    Force structure objective value evaluation routine.
' **
' **    This program reads in the results of the three CFAM scenario runs and
' **    calculates 1) the objective value for each scenario, and 2) the objective value
' **    for the multi-scenario. It outputs the multi-scenario evaluation to a file called
' **    evalue.txt for use by the GENESIS GA. It also outputs a summary of the
' **    structure evaluation to a file called report.txt. This one line summary includes the
' **    evaluated force structure, the three scenario objective function values, and the
' **    total multi-scenario objective function value.
' **
' **    Written by: Barry D. Bennett Jr.
' **
' **    Language: Visual Basic 6.0
' **
' *****************************************

Private Sub Form_Load()
   Dim txt As String
   Dim Acft() As String
   Dim AcftType As String
   Dim temp() As String
   Dim D(15) As Double
   Dim C() As String
   Dim A() As String
   Dim B() As String
   Dim O As Double, O1 As Double, O2 As Double, O3 As Double
   Dim I As Integer, J As Integer, L As Integer, LM As Integer, Atotal As Integer
   Dim C1 As Integer, C2 As Integer, C3 As Integer
   Dim Acft8 As Integer, Acft9 As Integer, Acft10 As Integer, Acft18 As Integer
   Dim Acft19 As Integer
   Open "C:\Cfam99~1\Outfiles\acc2-a00.csv" For Input As #1
   Open "C:\Cfam99~1\Outfiles\acc2-a01.csv" For Input As #2
   Open "C:\Cfam99~1\Outfiles\acc2-a02.csv" For Input As #3
   Open "C:\Cfam99~1\Outfiles\Object.txt" For Output As #4
   Open "C:\Cfam99~1\Infiles\tempobj.txt" For Output As #8
   Open "C:\Cfam99~1\Infiles\numacft.txt" For Input As #6
   Open "C:\Cfam99~1\Infiles\evalue.txt" For Output As #7
   Atotal = 0
   I = 0
```

```
' *******************************
' **
' ** Calculate total number of Aircraft in Force Structure
' **
' *******************************
  Line Input #6, AcftType
  Acft = Split(SuperTrim(AcftType))
  For k = LBound(Acft) To UBound(Acft)
    If k = 0 Then Acft8 = Acft(k)
    If k = 1 Then Acft9 = Acft(k)
    If k = 2 Then Acft10 = Acft(k)
    If k = 3 Then Acft18 = Acft(k)
    If k = 4 Then Acft19 = Acft(k)
  Next k
  Atotal = Acft8 + Acft9 + Acft10 + Acft18 + Acft19

  Print #4, "Total number of Aircraft =", Atotal

' ***********************************
' **
' ** Calculate Scenario 1 Objective Function Parameters
' **
' ***********************************


  Do
    Line Input #1, txt
    A = Split(SuperTrim(txt), ",")
     J = LBound(A)
     L = UBound(A)

    If UBound(A) <> -1 Then

      For k = LBound(A) To UBound(A)
        If A(k) = "1.00" Then
          D(0) = A(2)
          C1 = InStr(1, A(3), "YES")
          If C1 <> 0 Then
            D(1) = 1
          Else
            D(1) = 0
          End If
          D(2) = A(4)
          D(3) = A(6)
          D(4) = A(8)
        End If
```

```
        Next k
      End If

    Loop Until EOF(1)

' ***********************************
' **
' **  Calculate Scenario 2 Objective Function Parameters
' **
' ***********************************

    Do
      Line Input #2, txt
      A = Split(SuperTrim(txt), ",")
       J = LBound(A)
       L = UBound(A)

      If UBound(A) <> -1 Then

        For k = LBound(A) To UBound(A)
          If A(k) = "1.00" Then
            D(5) = A(2)
            C1 = InStr(1, A(3), "YES")
            If C1 <> 0 Then
              D(6) = 1
            Else
              D(6) = 0
            End If
            D(7) = A(4)
            D(8) = A(6)
            D(9) = A(8)
          End If

        Next k
      End If

    Loop Until EOF(2)
```

```
‘ ***********************************
‘ **
‘ **  Calculate Scenario 3 Objective Function Parameters
‘ **
‘ ***********************************

  Do
    Line Input #3, txt
    A = Split(SuperTrim(txt), ",")
     J = LBound(A)
     L = UBound(A)

    If UBound(A) <> -1 Then

       For k = LBound(A) To UBound(A)
         If A(k) = "1.00" Then
            D(10) = A(2)
            C1 = InStr(1, A(3), "YES")
            If C1 <> 0 Then
               D(11) = 1
            Else
               D(11) = 0
            End If
            D(12) = A(4)
            D(13) = A(6)
            D(14) = A(8)
         End If

       Next k
    End If

  Loop Until EOF(3)

‘ ***********************************
‘ **
‘ **     Calculate the three scenario objective values:  O1, O2, O3
‘ **
‘ ***********************************

  O1 = (-50 * D(0)) + 10000 * D(1) + 125 * D(2) - 50 * D(3) - 5 * D(4) - 50 * (Atotal)
  O2 = (-50 * D(5)) + 10000 * D(6) + 125 * D(7) - 50 * D(8) - 5 * D(9) - 50 * (Atotal)
  O3 = (-50 * D(10)) + 10000 * D(11) + 125 * D(12) - 50 * D(13) - 5 * D(14) - 50 *
(Atotal)
```

```
‘ ************************************
‘ **
‘ **    Calculate the multi-scenario objective values: O
‘ **    using equal probabilities of occurrence for each scenario.
‘ **
‘ ************************************

   O = (O1 / 3) + (O2 / 3) + (O3 / 3)
   Print #4, "Objective values = ", O1, O2, O3, O

‘ ************************************
‘ **    Append to file report.txt the analyzed force structure, objective values obtained in
‘ **    each scenario, and the overall objective function value.
‘ **
‘ ************************************
   Open "C:\Cfam99~1\Infiles\report.txt" For Append As #5
   Print #5, Acft8; Tab(7); Acft9; Tab(12); Acft10; Tab(17); Acft18; Tab(22); Acft19;
Tab(27); O1; Tab(37); O2; Tab(47); O3; Tab(57); O
   Close #5
   Print #8, Acft8; Tab(7); Acft9; Tab(12); Acft10; Tab(17); Acft18; Tab(22); Acft19;
Tab(27); O1; Tab(37); O2; Tab(47); O3; Tab(57); O

‘ ************************************
‘ **
‘ **    Write to file evalue.txt the multi-scenario objective function value used by
‘ **    GENESIS GA.
‘ **
‘ ************************************

   Print #7, O
   Close #1
   Close #2
   Close #3
   Close #4
   Close #6
   Close #7
   Close #8
   End
End Sub
‘ ************************************
‘ **
‘ ** Subroutine to reduce the number of blank spaces between words on a line of text to
‘ ** one.
‘ **
‘ ************************************
Public Function SuperTrim(TheString As String) As String
```

```
    Dim temp As String, DoubleSpaces As String
    DoubleSpaces = Chr(32) & Chr(32)
    temp = Trim(TheString)
    temp = Replace(temp, DoubleSpaces, Chr(32))
    Do Until InStr(temp, DoubleSpaces) = 0
        temp = Replace(temp, DoubleSpaces, Chr(32))
    Loop
    SuperTrim = temp
End Function

' *********** End of Objvalue.exe program ******************
```

Appendix 7: Raw Data, Candidate Structure CFAM Evaluation Runs

	Aircraft Number by Type					Fitness Value			Total
Trials	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Fitness
1	9	19	3	63	42	3289.00	3259.50	3285.00	3277.83
2	24	30	21	39	27	2960.50	-7071.50	2981.50	-376.50
3	51	12	0	8	46	4179.00	-5855.00	4196.00	840.00
4	63	7	6	38	63	1236.00	1229.00	1247.00	1237.33
5	37	33	8	47	1	3654.50	-6341.00	-6327.50	-3004.67
6	29	24	4	26	39	3913.00	-6109.00	3948.50	584.17
7	32	4	22	7	55	4042.00	-5996.00	4056.00	700.67
8	2	48	24	56	43	1421.50	1387.50	1441.50	1416.83
9	35	52	45	53	2	617.00	-9391.00	657.00	-2705.67
10	25	10	35	31	19	3956.00	-6023.50	-6010.50	-2692.67
11	14	44	45	22	31	2201.00	-7830.00	2233.00	-1132.00
12	22	59	52	8	9	2434.00	-7548.50	-7533.50	-4216.00
13	17	17	55	17	6	4340.00	-5646.00	-5623.00	-2309.67
14	49	54	35	9	18	1721.00	-8291.50	-8281.50	-4950.67
15	23	15	45	58	2	2824.50	-7182.00	2875.00	-494.17
16	15	57	53	25	41	477.00	-9571.00	523.00	-2857.00
17	4	62	49	58	7	986.00	-9034.50	1011.50	-2345.67
18	32	35	60	54	1	865.50	-9147.00	905.00	-2458.83
19	25	55	13	29	55	1222.50	1174.00	1232.50	1209.67
20	52	14	40	31	19	2181.50	-7840.00	2219.00	-1146.50
21	61	50	33	55	47	-2224.00	-2236.00	-2189.00	-2216.33
22	17	22	1	23	56	4105.50	-5950.00	4114.00	756.50
23	40	21	62	18	34	1269.00	-8780.50	1276.50	-2078.33
24	28	15	42	0	22	4616.00	-5381.00	-5366.50	-2043.83
25	13	61	30	49	26	1078.50	-8983.50	1124.00	-2260.33
26	56	41	40	16	12	1713.00	-8301.00	-8292.00	-4960.00
27	37	37	11	45	20	2502.00	-7532.50	2519.50	-837.00
28	29	59	4	52	45	623.00	566.00	625.00	604.67
29	0	31	46	44	15	3182.00	-6827.50	-6810.50	-3485.33
30	49	14	54	20	36	1360.50	-8680.50	1372.50	-1982.50
31	57	30	21	39	47	367.00	317.50	368.50	351.00
32	29	50	33	55	27	340.00	321.50	368.50	343.33
33	40	24	4	18	34	4019.00	-6022.50	4040.00	678.83
34	29	21	62	26	39	1170.50	-8873.50	1179.00	-2174.67
35	13	15	24	56	43	2523.00	2498.50	2556.00	2525.83
36	52	49	40	31	19	431.50	-9588.00	457.00	-2899.83
37	17	22	1	10	7	7047.00	-2887.00	-2865.50	431.50
38	35	52	45	40	61	-1565.50	-1581.50	-1532.50	-1559.83
39	37	55	13	29	55	622.50	575.50	621.50	606.50
40	25	37	11	45	20	3102.00	-6919.00	3132.50	-228.17
41	2	24	4	26	36	5431.50	-4598.50	-4578.50	-1248.50
42	29	48	24	56	40	217.50	164.00	217.00	199.50

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
43	29	59	6	7	45	2729.50	-7300.00	2738.00	-610.83
44	32	4	20	52	55	1930.50	1893.50	1953.50	1925.83
45	4	62	50	58	7	936.00	-9084.50	961.50	-2395.67
46	23	15	46	58	2	2774.50	-7232.50	2824.50	-544.50
47	14	44	46	45	31	1037.00	-9031.00	1072.50	-2307.17
48	0	31	45	23	15	4244.00	-5733.00	-5713.50	-2400.83
49	9	19	3	63	37	3518.50	-6541.00	3513.00	163.50
50	49	14	54	20	43	1026.00	-9029.00	1027.00	-2325.33
51	15	57	54	25	41	432.00	-9616.00	468.00	-2905.33
52	13	61	29	49	26	1128.50	-8928.50	1174.00	-2208.67
53	57	30	20	52	55	-619.00	-630.00	-579.00	-609.33
54	32	4	21	39	47	2911.50	-7156.00	2898.00	-448.83
55	63	7	13	38	63	886.00	880.50	889.00	885.17
56	4	62	57	58	7	586.00	-9439.50	609.50	-2748.00
57	37	50	13	29	55	872.50	820.00	879.50	857.33
58	29	55	33	55	27	90.00	67.00	116.50	91.17
59	17	54	1	10	7	5475.50	-4498.00	-4477.00	-1166.50
60	25	23	13	29	55	2810.50	2792.00	2845.50	2816.00
61	37	55	14	58	2	1674.50	-8345.00	1706.50	-1654.67
62	23	15	45	29	55	1722.50	1685.00	1738.00	1715.17
63	29	55	30	55	27	240.00	222.00	262.50	241.50
64	63	2	57	38	63	-1064.00	-1076.50	-1027.50	-1056.00
65	8	24	9	25	41	4671.50	-5350.00	4709.50	1343.67
66	47	57	59	18	34	-731.00	-10778.50	-738.50	-4082.67
67	15	7	3	63	42	3588.00	-6491.00	3564.50	220.50
68	57	19	6	38	63	936.00	929.50	958.50	941.33
69	28	15	42	55	41	1018.50	975.50	1028.50	1007.50
70	29	48	24	0	23	3771.50	-6237.50	-6217.00	-2894.33
71	50	59	7	8	46	1531.00	-8518.00	1525.50	-1820.50
72	28	12	1	7	50	5153.00	-4895.50	-4885.50	-1542.67
73	10	61	29	49	26	1278.50	-8781.50	1275.50	-2075.83
74	18	48	25	10	7	4531.50	-5451.50	-5430.50	-2116.83
75	30	22	0	56	40	2659.00	2643.00	2697.50	2666.50
76	13	15	24	56	52	2086.50	2046.50	2107.50	2080.17
77	18	55	30	10	7	3931.50	-6049.00	-6032.00	-2716.50
78	30	54	1	55	27	1690.00	1669.50	1725.50	1695.00
79	26	50	0	56	40	1467.50	1432.50	1476.50	1458.83
80	33	22	13	29	55	2470.50	2437.00	2495.00	2467.50
81	57	51	3	52	55	-819.00	-829.00	-783.00	-810.33
82	51	30	23	8	46	2131.00	-7919.50	2135.50	-1217.67
83	28	15	45	8	41	3174.50	-6865.50	3192.00	-166.33
84	25	23	10	34	55	2718.00	2691.50	2747.00	2718.83
85	50	27	7	8	46	3131.00	-6913.50	3140.50	-214.00
86	57	51	6	38	63	-664.00	-676.00	-631.00	-657.00
87	13	15	45	24	20	4107.00	-5869.50	-5853.00	-2538.50
88	23	15	24	61	55	1172.00	1186.50	1196.50	1185.00

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
89	9	7	13	63	37	3629.00	-6441.50	3614.00	267.17
90	63	19	3	38	63	786.00	776.00	827.50	796.50
91	9	16	14	58	42	3130.00	3103.00	3123.50	3118.83
92	37	52	3	63	2	2130.00	-7889.50	2164.00	-1198.50
93	56	7	13	38	63	1236.00	1181.00	1238.50	1218.50
94	62	19	6	38	63	686.00	675.50	727.50	696.33
95	24	24	9	29	55	3014.50	2989.00	3053.00	3018.83
96	9	23	13	25	41	4469.00	-5550.00	4509.00	1142.67
97	13	61	29	56	43	-28.00	-77.50	-20.50	-42.00
98	10	15	24	49	26	3819.50	-6199.00	3849.00	489.83
99	61	55	33	55	63	-3265.00	-3277.00	-3235.50	-3259.17
100	31	2	58	38	27	2209.50	-7818.50	2228.50	-1126.83
101	13	15	24	56	40	2667.00	2647.00	-7400.00	-695.33
102	30	22	0	56	52	2074.00	2040.00	2100.00	2071.33
103	15	7	3	63	37	3830.00	-6241.00	3813.50	467.50
104	23	15	0	56	40	3371.00	3350.50	3353.50	3358.33
105	26	50	24	61	55	-719.00	-734.00	-676.00	-709.67
106	15	4	3	63	37	3981.00	-6088.50	3966.50	619.67
107	37	55	3	63	2	1980.00	-8046.00	2013.00	-1351.00
108	51	30	23	8	26	3095.00	-6933.50	-6918.50	-3585.67
109	30	54	1	55	47	726.00	717.50	737.00	726.83
110	25	37	10	34	20	3689.00	-6324.00	3735.00	366.67
111	31	13	59	41	27	1463.00	-8581.00	1477.50	-1880.17
112	14	22	13	31	43	3882.00	-6146.00	3907.50	547.83
113	33	61	29	58	55	-1719.00	-1729.00	-1684.00	-1710.67
114	10	15	14	58	42	3130.00	3103.00	3118.00	3117.00
115	9	16	24	49	26	3819.50	-6204.00	3849.00	488.17
116	6	51	3	56	52	1664.00	1638.50	1696.00	1666.17
117	33	22	0	52	55	1970.00	1938.50	1992.50	1967.00
118	28	15	13	0	50	4733.00	-5304.00	-5294.50	-1955.17
119	9	20	1	25	41	5244.00	-4794.50	-4778.50	-1443.00
120	30	7	1	55	27	4031.00	-5999.00	-6000.00	-2656.00
121	56	54	13	38	63	-1114.00	-1120.50	-1083.00	-1105.83
122	13	15	6	39	40	4390.00	-5639.00	4411.00	1054.00
123	57	51	24	57	63	-2515.00	-2522.50	-2484.50	-2507.33
124	9	7	13	63	41	3435.50	-6641.00	3414.00	69.50
125	28	15	45	8	37	3369.00	-6665.50	-6660.00	-3318.83
126	23	12	60	34	40	1595.00	-8471.50	1635.00	-1747.17
127	63	16	24	57	63	-1065.00	-1074.50	-1025.50	-1055.00
128	48	24	9	29	55	1822.50	1778.50	1837.00	1812.67
129	26	27	7	8	46	4321.00	-5706.00	4350.00	988.33
130	25	23	10	34	48	3054.50	-6998.50	3050.50	-297.83
131	24	24	10	29	55	2963.50	2938.50	2997.50	2966.50
132	1	54	14	58	42	1620.00	1588.50	1642.50	1617.00
133	21	15	1	55	32	3841.50	-6201.50	3853.00	497.67
134	9	19	1	39	42	4550.00	-5484.50	4565.00	1210.17
135	13	15	3	63	40	3384.50	3353.50	3374.00	3370.67
136	20	12	60	34	40	1745.00	-8319.50	1736.50	-1612.67

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
137	9	19	3	63	42	3289.00	3259.50	3285.00	3277.83
138	30	52	7	8	46	2881.00	-7165.50	2889.50	-465.00
139	26	25	1	55	47	2370.00	2340.00	2400.50	2370.17
140	24	24	6	34	40	3633.50	-6401.50	3655.50	295.83
141	62	19	10	25	63	1132.00	1073.50	1129.00	1111.50
142	10	12	1	58	42	3938.50	-6137.00	3918.00	573.17
143	6	48	12	56	52	1361.50	1336.00	1393.50	1363.67
144	62	23	21	34	48	664.00	623.50	671.00	652.83
145	24	16	24	57	63	872.00	886.50	941.00	899.83
146	23	7	9	29	55	3910.50	-6132.00	3914.00	564.17
147	48	16	0	56	40	2066.50	2029.50	2082.50	2059.50
148	24	25	10	29	55	2912.00	2887.50	2951.50	2917.00
149	33	23	0	52	55	1918.00	1887.50	1946.50	1917.33
150	37	55	0	55	2	2520.50	-7498.00	2565.00	-804.17
151	33	22	3	60	55	1416.00	1434.50	1443.50	1431.33
152	15	4	3	63	37	3981.00	-6088.50	3966.50	619.67
153	14	22	10	31	43	4035.50	-5990.00	4058.50	701.33
154	33	61	29	63	40	-1230.00	-1238.50	-1188.50	-1219.00
155	9	7	13	58	54	3062.50	3013.00	3070.50	3048.67
156	32	24	6	36	55	2411.50	2389.00	2447.00	2415.83
157	25	23	0	50	40	3158.00	3141.50	3200.00	3166.50
158	13	15	3	57	63	2565.00	2518.50	2572.50	2552.00
159	62	19	10	31	40	1940.50	1919.00	1975.00	1944.83
160	10	12	0	63	42	3742.00	-6338.00	3717.00	373.67
161	9	19	2	58	42	3577.50	-6489.00	3562.00	216.83
162	62	23	21	58	48	-523.00	-532.50	-481.50	-512.33
163	9	7	13	34	54	4231.50	-5826.50	4223.00	876.00
164	25	61	29	34	20	1539.00	-8484.00	1570.00	-1791.67
165	33	37	10	63	40	920.00	869.50	929.50	906.33
166	57	20	13	38	63	536.00	525.00	577.50	546.17
167	8	54	1	25	41	3570.50	-6455.00	3593.00	236.17
168	50	15	1	55	40	2017.00	1978.00	2036.50	2010.50
169	33	23	3	60	55	1365.50	1384.00	1397.50	1382.33
170	21	15	1	58	47	2987.00	2953.50	-7100.00	-386.50
171	1	54	14	55	37	2010.50	1983.00	2041.50	2011.67
172	48	16	24	56	40	867.50	824.00	879.00	856.83
173	24	16	0	57	63	2099.00	2061.00	2111.50	2090.50
174	23	15	24	29	55	2764.00	2754.00	2803.00	2773.67
175	9	24	9	49	26	4167.50	-5857.00	4199.00	836.50
176	33	22	0	56	55	1770.00	1742.00	1796.50	1769.50
177	23	15	3	60	55	2294.50	2249.50	2306.00	2283.33
178	9	24	1	39	42	4301.00	-5737.50	4312.00	958.50
179	26	18	1	55	47	2728.50	2700.00	2751.00	2726.50
180	6	48	12	48	36	2530.50	-7514.00	2542.00	-813.83
181	15	4	0	56	53	3708.50	3662.50	3672.00	3681.00
182	9	19	3	63	37	3518.50	-6541.00	3513.00	163.50
183	50	57	14	55	40	-733.00	-781.00	-691.50	-735.17
184	1	15	1	55	37	4639.00	-5435.50	-5421.00	-2072.50

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
185	33	22	9	36	55	2310.00	2288.00	2346.50	2314.83
186	32	24	0	56	55	1718.00	1686.50	1745.50	1716.67
187	27	16	0	56	47	2780.50	2750.50	2807.50	2779.50
188	25	18	1	54	63	2044.00	2003.50	2059.00	2035.50
189	63	12	10	31	40	2240.50	-7827.00	2282.00	-1101.50
190	22	16	3	60	55	2294.50	2254.50	2311.00	2286.67
191	33	36	0	63	40	1470.00	1425.00	1481.50	1458.83
192	10	13	10	63	42	3189.50	3154.50	3170.00	3171.33
193	8	53	1	25	41	3614.00	-6409.50	3643.50	282.67
194	57	23	13	38	63	386.00	374.00	427.00	395.67
195	23	15	26	29	55	2662.50	2638.00	2696.50	2665.67
196	14	22	8	16	43	4896.50	-5146.00	-5137.00	-1795.50
197	9	7	13	34	63	3799.00	-6277.50	3774.50	432.00
198	13	15	3	57	54	3005.00	-7100.00	3018.50	-358.83
199	9	24	3	63	42	3034.00	3007.00	3060.00	3033.67
200	13	15	1	39	40	4648.00	-5391.00	4665.00	1307.33
201	32	24	6	37	43	2940.00	-7113.00	2943.50	-409.83
202	9	19	2	59	54	2957.50	2921.00	2969.50	2949.33
203	30	52	0	50	46	1173.50	1120.50	1180.50	1158.17
204	25	23	7	8	40	4872.50	-5159.50	-5150.00	-1812.33
205	41	24	9	49	26	2578.50	-7470.00	2579.00	-770.83
206	9	19	2	56	54	3105.50	3066.50	3119.00	3097.00
207	32	24	0	59	55	1568.00	1580.50	1589.50	1579.33
208	57	23	3	60	55	181.00	173.50	228.00	194.17
209	22	16	13	38	63	2491.00	2449.50	2505.00	2481.83
210	22	16	3	63	55	2144.50	2099.50	2160.50	2134.83
211	25	18	1	53	63	2094.00	2049.00	2109.50	2084.17
212	4	16	0	38	41	5134.50	-4939.00	-4926.00	-1576.83
213	40	53	1	7	47	2632.00	-7413.50	2637.50	-714.67
214	9	15	1	58	47	3591.50	3561.00	3565.50	3572.67
215	21	7	13	34	63	3193.50	3158.00	3217.50	3189.67
216	1	15	1	55	40	4492.00	-5581.00	4474.50	1128.50
217	25	23	7	8	37	5017.50	-5010.00	-5000.50	-1664.33
218	48	16	24	59	40	719.00	673.00	728.00	706.67
219	33	22	9	39	55	2162.00	2148.00	2196.00	2168.67
220	33	50	10	63	40	270.00	262.50	317.00	283.17
221	10	27	0	63	42	2982.00	2951.00	3009.00	2980.67
222	9	24	28	29	55	2816.50	-7252.00	2810.50	-541.67
223	23	15	26	63	42	1610.00	1584.50	1639.50	1611.33
224	9	24	26	31	42	3429.50	-6600.00	3455.00	94.83
225	23	15	3	61	55	2244.50	2205.00	2255.50	2235.00
226	15	24	6	37	53	3327.00	-6738.50	3334.00	-25.83
227	32	4	0	56	43	3328.00	-6750.00	3356.00	-22.00
228	15	7	13	34	63	3499.50	-6578.00	3489.50	137.00
229	21	4	0	56	53	3408.50	3361.50	3417.50	3395.83
230	24	4	1	55	47	3542.50	3508.00	3526.00	3525.50
231	34	18	0	56	43	2513.50	2493.00	2548.50	2518.33
232	9	19	1	55	47	3542.50	3508.50	3524.50	3525.17

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
233	26	18	2	39	54	3129.00	3098.50	3154.00	3127.17
234	23	15	1	63	42	2880.50	2854.50	2907.50	2880.83
235	9	15	26	58	47	2333.50	2302.00	2360.50	2332.00
236	26	16	1	55	40	3167.00	3148.00	3203.50	3172.83
237	1	13	1	55	47	4252.00	-5826.50	4228.50	884.67
238	25	22	9	39	55	2574.00	2542.50	2603.00	2573.17
239	33	23	7	8	37	4602.00	-5413.50	-5406.50	-2072.67
240	57	23	3	60	53	280.00	278.00	327.00	295.00
241	16	4	0	56	55	3560.00	3516.00	3530.50	3535.50
242	48	16	24	59	47	376.00	368.00	424.00	389.33
243	9	15	1	58	40	3931.50	-6139.50	3915.50	569.17
244	23	15	3	63	55	2144.50	2099.50	2155.50	2133.17
245	22	16	3	61	55	2244.50	2210.00	2261.00	2238.50
246	33	51	0	63	40	720.00	710.00	730.00	720.00
247	30	53	10	50	46	623.50	567.00	621.50	604.00
248	15	24	13	37	53	2973.50	2947.00	3007.00	2975.83
249	22	16	6	38	63	2845.50	2803.50	2864.00	2837.67
250	24	4	0	55	47	3593.00	3558.00	3571.00	3574.00
251	21	4	1	56	53	3357.50	3311.50	3367.50	3345.50
252	57	23	3	34	63	1085.50	1069.50	1089.00	1081.33
253	15	7	13	60	53	2704.50	2659.00	2717.50	2693.67
254	10	27	0	59	54	2597.50	2556.00	2615.50	2589.67
255	32	24	1	63	43	1908.50	1884.00	1938.50	1910.33
256	54	16	24	59	47	76.00	69.50	122.00	89.17
257	15	15	26	58	47	2027.50	1997.50	2053.50	2026.17
258	9	18	1	55	47	3589.50	3559.00	3575.00	3574.50
259	1	12	1	48	40	4996.50	-5083.50	-5069.00	-1718.67
260	23	15	14	63	42	2222.50	2195.50	2253.50	2223.83
261	34	18	0	56	43	2513.50	2493.00	2548.50	2518.33
262	25	15	25	39	55	2119.00	2090.00	2149.50	2119.50
263	9	22	10	58	47	2787.00	-7300.00	2812.00	-567.00
264	33	18	0	56	40	2710.00	2693.50	2743.50	2715.67
265	34	51	0	60	43	673.00	665.50	675.00	671.17
266	22	16	6	61	48	2435.50	2401.00	2459.00	2431.83
267	22	16	3	38	56	3335.00	3303.00	3362.00	3333.33
268	15	24	13	37	58	2732.50	2697.50	2758.50	2729.50
269	25	18	1	53	48	2829.50	2801.00	2858.00	2829.50
270	26	18	29	39	54	1775.50	1741.50	1794.00	1770.33
271	30	55	5	50	46	773.50	722.50	772.00	756.00
272	32	26	14	63	43	1173.00	1126.00	1178.50	1159.17
273	26	20	0	56	55	2236.00	2195.50	2256.00	2229.17
274	16	2	29	39	54	3081.50	-6986.00	3077.00	-275.83
275	23	15	0	63	42	2931.00	2900.00	2957.50	2929.50
276	24	4	14	55	47	2884.50	2853.00	2910.50	2882.67
277	27	16	5	56	47	2527.50	2499.00	2554.00	2526.83
278	15	15	31	58	47	1773.00	1745.50	1801.00	1773.17
279	15	56	13	60	52	279.00	276.50	328.00	294.50
280	9	24	28	29	54	2864.50	-7202.00	2855.50	-494.00

Trials	Aircraft Number by Type					Fitness Value			Total
Trials	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Fitness
281	22	16	1	55	47	3033.50	3002.50	3060.00	3032.00
282	9	18	6	61	48	2997.50	2957.00	3015.00	2989.83
283	33	17	3	56	40	2608.50	2593.00	2648.00	2616.50
284	22	18	0	38	59	3240.00	3203.50	3264.00	3235.83
285	30	16	25	39	55	1824.50	1787.00	1844.00	1818.50
286	38	8	3	60	55	1882.50	1842.00	1898.00	1874.17
287	25	18	1	53	52	2635.00	2602.50	2658.00	2631.83
288	21	4	1	56	49	3549.00	3510.00	3524.00	3527.67
289	53	27	0	59	47	776.00	772.50	824.00	790.83
290	9	16	24	59	54	1993.00	1954.50	2010.50	1986.00
291	29	18	0	56	42	2818.50	2796.50	2853.00	2822.67
292	48	4	0	56	52	2067.50	2039.50	2099.50	2068.83
293	26	18	1	55	55	2338.00	2297.00	2358.00	2331.00
294	23	15	3	63	47	2537.50	2506.00	2559.50	2534.33
295	33	18	0	55	40	2759.00	2743.50	2798.50	2767.00
296	23	15	3	56	47	2883.50	2852.00	2910.00	2881.83
297	27	16	5	63	47	2180.00	2142.50	2203.50	2175.33
298	9	16	6	61	48	3100.00	3063.00	3115.50	3092.83
299	22	18	3	38	56	3234.50	3202.00	3211.50	3216.00
300	26	18	2	39	55	3081.00	3048.00	3109.00	3079.33
301	16	2	31	55	54	2194.00	2155.00	2214.50	2187.83
302	30	19	1	56	55	2030.50	1992.50	2047.50	2023.50
303	21	7	25	39	49	3019.00	-7046.00	3030.50	-332.17
304	26	27	0	59	40	2459.50	2436.00	2497.00	2464.17
305	53	16	1	55	47	1476.00	1436.50	1485.50	1466.00
306	34	18	31	56	43	972.00	924.00	978.50	958.17
307	15	15	0	58	47	3344.50	3306.50	3362.50	3337.83
308	38	8	3	60	43	2471.50	2446.00	2501.00	2472.83
309	32	26	14	63	55	581.00	577.00	634.50	597.50
310	33	17	3	56	55	1875.50	1840.00	1900.00	1871.83
311	15	4	0	56	42	4239.00	-5834.00	4226.00	877.00
312	9	18	0	41	59	3748.00	-6350.00	3730.50	376.17
313	27	4	14	56	47	2683.00	2651.50	2709.00	2681.17
314	22	15	3	38	56	3385.00	3358.50	3412.00	3385.17
315	48	27	0	56	52	929.50	927.00	978.00	944.83
316	41	15	6	19	29	4495.00	-5519.00	-5505.00	-2176.33
317	22	34	52	63	61	-1516.50	-1527.00	-1474.50	-1506.00
318	22	62	11	9	22	3683.50	-6334.50	-6318.50	-2989.83
319	36	16	24	25	14	4204.00	-5780.50	-5767.50	-2448.00
320	2	31	10	60	42	2828.00	2800.50	2858.00	2828.83
321	40	30	23	37	38	1644.00	1618.50	1680.00	1647.50
322	6	27	26	24	44	3668.00	-6346.50	3706.50	342.67
323	41	4	43	6	8	4829.00	-5147.50	-5129.00	-1815.83
324	63	20	10	51	2	2661.50	-7346.00	2714.50	-656.67
325	33	1	48	12	21	4234.50	-5780.50	-5764.50	-2436.83
326	33	25	19	25	63	1832.00	1786.00	1848.00	1822.00
327	29	33	29	23	22	3174.00	-6800.00	-6824.50	-3483.50
328	1	0	55	7	55	4162.00	-5892.00	-5878.50	-2536.17

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
329	4	63	56	59	61	-2066.00	-2071.00	-2026.00	-2054.33
330	29	11	11	33	39	3870.50	-6150.00	3907.00	542.50
331	0	35	56	30	50	1515.00	-8557.50	1537.50	-1835.00
332	4	59	52	9	7	3378.00	-6602.50	-6581.50	-3268.67
333	8	32	34	9	47	3523.50	-6507.00	3556.00	190.83
334	17	15	18	52	56	2189.00	2148.50	2209.00	2182.17
335	8	26	56	7	46	2880.50	-7161.50	2897.50	-461.17
336	22	52	28	35	44	1006.50	974.50	1024.00	1001.67
337	14	55	26	14	18	3628.50	-6388.00	-6367.00	-3042.17
338	45	54	23	20	12	2254.50	-7748.50	-7733.00	-4409.00
339	35	61	10	54	14	1297.50	-8735.50	1319.00	-2039.67
340	2	38	50	4	25	4034.50	-5978.00	-5960.00	-2634.50
341	47	14	27	49	25	1925.50	-8131.00	1975.50	-1410.00
342	33	17	6	18	18	5376.50	-4628.00	-4611.50	-1287.67
343	51	45	39	29	32	211.50	-9831.50	263.50	-3118.83
344	48	30	0	17	43	3131.00	-6920.50	3136.50	-217.67
345	42	22	61	46	56	-1268.50	-1279.00	-1230.50	-1259.33
346	40	30	23	39	25	2156.50	-7883.00	2177.00	-1183.17
347	8	26	56	5	46	2980.00	-7060.50	-7047.50	-3709.33
348	47	6	19	25	63	2082.00	2043.50	2096.00	2073.83
349	33	17	27	49	25	2475.50	-7573.50	2482.50	-871.83
350	50	33	7	29	32	2461.50	-7581.00	2480.00	-879.83
351	48	18	32	17	43	2131.00	-7926.00	2134.00	-1220.33
352	1	1	48	12	21	5830.50	-4174.00	-4150.50	-831.33
353	32	35	56	30	50	-86.00	-124.50	-76.00	-95.50
354	33	16	43	6	10	4535.00	-5443.50	-5429.00	-2112.50
355	41	5	6	18	16	5673.00	-4326.50	-4309.50	-987.67
356	59	16	24	25	14	3064.50	-6941.00	-6926.00	-3600.83
357	34	31	13	61	56	331.50	329.00	383.00	347.83
358	10	22	61	47	42	964.50	928.00	987.00	959.83
359	35	58	10	54	14	1447.50	-8591.00	1465.50	-1892.67
360	40	30	23	37	57	731.00	676.00	732.00	713.00
361	17	15	18	52	39	3010.50	2998.50	3002.00	3003.67
362	9	52	29	9	47	2732.50	-7313.50	2743.50	-612.50
363	23	32	35	35	44	1606.50	1575.50	1634.50	1605.50
364	29	11	11	35	39	3767.50	-6250.00	3806.50	441.33
365	1	0	55	6	55	4212.00	-5841.50	-5828.00	-2485.83
366	17	15	6	19	28	5766.00	-4262.00	-4250.00	-915.33
367	41	15	18	52	57	932.50	933.00	951.50	939.00
368	6	28	26	24	44	3620.50	-6400.00	3656.00	292.17
369	22	52	28	32	44	1152.50	1124.50	1174.50	1150.50
370	15	32	34	38	47	1766.00	1731.50	1790.50	1762.67
371	40	30	23	10	57	2041.50	-8015.00	2087.50	-1295.33
372	32	58	13	54	16	1351.50	-8690.00	1366.00	-1990.83
373	41	5	6	18	14	5766.00	-4232.00	-4215.00	-893.67
374	9	22	61	47	42	1014.50	979.00	1037.50	1010.33
375	18	15	18	52	39	2960.00	2942.50	2975.50	2959.33
376	33	17	27	25	62	1880.50	1837.50	1889.50	1869.17

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
377	33	25	19	49	24	2522.50	-7525.00	2530.50	-824.00
378	41	15	19	35	44	2356.50	2332.00	2388.50	2359.00
379	23	32	34	52	57	182.50	172.50	229.50	194.83
380	33	16	43	6	11	4486.50	-5493.00	-5479.00	-2161.83
381	38	28	26	29	56	1224.00	1175.00	1230.50	1209.83
382	2	31	13	56	44	2777.00	2750.50	2808.00	2778.50
383	46	9	19	25	63	1982.00	1937.50	1994.50	1971.33
384	17	0	18	52	39	3765.00	-6294.50	3765.50	412.00
385	4	19	24	25	14	5678.00	-4323.00	-4307.50	-984.17
386	32	32	56	30	50	64.00	20.50	71.00	51.83
387	50	32	7	29	39	2179.00	-7874.50	2180.00	-1171.83
388	29	10	11	35	39	3819.00	-6199.50	3857.00	492.17
389	6	28	27	24	44	3571.00	-6447.00	3605.50	243.17
390	48	18	33	17	43	2081.00	-7976.50	2078.50	-1272.33
391	33	25	19	30	63	1585.00	1535.00	1586.50	1568.83
392	17	15	6	20	28	5718.00	-4312.50	-4293.50	-962.67
393	2	31	10	61	42	2779.00	2750.00	2808.50	2779.17
394	2	31	19	30	61	2933.50	2898.50	2912.00	2914.67
395	33	25	10	61	40	1619.00	1583.50	1636.50	1613.00
396	15	32	34	52	47	1075.50	1034.00	1087.50	1065.67
397	23	32	34	38	57	881.50	828.00	880.00	863.17
398	15	32	56	25	47	1300.50	-8768.00	1334.50	-2044.33
399	32	32	34	33	50	1017.00	972.50	1028.00	1005.83
400	32	59	18	54	16	1051.50	-8979.50	1114.50	-2271.17
401	17	14	13	52	39	3312.50	-6749.50	3314.50	-40.83
402	6	60	27	24	44	1991.00	-8069.50	1987.50	-1363.67
403	9	20	29	9	47	4339.50	-5700.50	-5689.00	-2350.00
404	9	23	13	47	45	3221.50	-6846.00	3218.00	-135.50
405	2	30	58	61	42	422.00	379.00	438.00	413.00
406	38	28	26	18	7	4095.00	-5897.00	-5875.50	-2559.17
407	41	5	6	29	46	3694.50	-6348.50	3701.50	349.17
408	5	28	24	25	14	5140.50	-4828.50	-4812.00	-1500.00
409	3	16	13	56	44	3480.00	-6585.50	3465.00	119.83
410	33	17	27	25	49	2505.50	-7564.00	2540.50	-839.33
411	41	15	19	35	35	2782.50	-7269.00	2786.00	-566.83
412	38	29	19	30	56	1475.00	1427.50	1486.50	1463.00
413	33	24	26	29	63	1334.50	1282.50	1340.00	1319.00
414	33	9	21	61	40	1855.50	1834.00	1894.00	1861.17
415	41	31	19	35	35	1982.50	-8080.00	1984.50	-1371.00
416	44	6	19	29	42	3040.00	-7013.00	3043.50	-309.83
417	2	30	58	57	63	-415.00	-413.50	-362.50	-397.00
418	17	25	18	52	39	2501.00	2492.00	2546.50	2513.17
419	33	14	12	30	63	2476.50	2449.00	2503.50	2476.33
420	41	25	10	61	49	777.50	772.50	828.50	792.83
421	33	5	6	29	40	4378.00	-5650.00	4404.50	1044.17
422	33	17	24	25	49	2655.50	-7408.00	2642.00	-703.50
423	50	32	4	29	39	2334.00	-7728.00	2331.00	-1021.00
424	22	54	19	24	44	1891.00	-8175.50	1886.00	-1466.17

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
425	46	11	28	33	63	1035.50	984.50	1037.50	1019.17
426	32	32	34	46	26	1523.50	-8524.00	1580.00	-1806.83
427	33	25	19	62	48	727.00	723.50	743.00	731.17
428	38	31	34	52	40	315.00	264.50	324.50	301.33
429	15	35	26	18	63	2196.00	2189.50	2242.50	2209.33
430	3	16	13	39	44	4305.00	-5732.50	4316.50	963.00
431	9	23	13	48	45	3172.50	-6891.50	3157.50	-187.17
432	41	3	20	35	44	2887.00	-7161.00	2896.50	-459.17
433	6	48	27	24	44	2591.00	-7458.50	2588.00	-759.83
434	22	52	28	32	47	1009.50	976.00	1030.00	1005.17
435	2	31	16	30	61	3085.50	-6994.50	3059.00	-283.33
436	41	25	10	61	41	1171.00	1122.50	1176.50	1156.67
437	33	5	6	29	48	3993.00	-6042.50	4007.00	652.50
438	25	31	34	49	56	332.00	322.50	377.00	343.83
439	38	29	19	27	40	2383.50	-7673.50	2384.00	-968.67
440	18	15	18	53	39	2911.00	2892.00	2950.50	2917.83
441	33	9	21	60	40	1905.00	1884.00	1944.00	1911.00
442	17	15	19	24	44	4077.50	-5949.50	4107.50	745.17
443	6	48	26	52	39	1513.50	1483.50	1537.50	1511.50
444	3	19	26	24	44	4225.00	-5795.00	4267.00	899.00
445	15	35	13	45	63	1523.50	1494.00	1547.00	1521.50
446	17	25	18	33	63	2280.50	2245.00	2304.50	2276.67
447	33	14	12	11	39	4567.50	-5462.50	-5448.50	-2114.50
448	33	16	28	32	47	2259.50	2238.50	2285.50	2261.17
449	22	53	24	25	49	1405.50	1377.50	1432.00	1405.00
450	17	0	18	52	39	3765.00	-6294.50	3765.50	412.00
451	41	16	19	35	35	2732.50	-7319.50	2735.00	-617.33
452	44	6	20	35	42	2700.00	-7364.50	2690.50	-658.00
453	29	10	12	29	39	4067.50	-5948.50	4102.50	740.50
454	2	31	18	52	61	1892.00	1850.00	1909.50	1883.83
455	18	15	16	30	39	4125.00	-5891.50	4161.00	798.17
456	18	25	18	52	39	2450.00	2435.00	2491.00	2458.67
457	17	15	18	52	39	3010.50	2998.50	3002.00	3003.67
458	33	24	50	48	47	-26.50	-83.00	-23.50	-44.33
459	9	22	19	62	50	1986.50	1946.00	2007.00	1979.83
460	33	9	21	63	40	1756.00	1743.50	1793.50	1764.33
461	47	6	13	38	63	1728.50	1688.00	1744.50	1720.33
462	15	35	19	18	63	2538.00	2542.50	2600.50	2560.33
463	2	28	18	52	61	2046.00	2008.00	2058.00	2037.33
464	47	6	18	33	63	1735.50	1687.50	1739.00	1720.67
465	17	25	19	25	63	2624.00	2595.00	2650.00	2623.00
466	23	32	19	24	44	2941.00	-7114.00	2947.50	-408.50
467	17	15	34	38	57	2024.50	1992.50	2047.00	2021.33
468	3	19	26	29	51	3652.50	-6388.50	3670.00	311.33
469	33	5	6	24	47	4287.00	-5742.50	4307.50	950.67
470	45	15	19	35	35	2582.50	-7466.50	2583.50	-766.83
471	22	16	18	53	39	2657.00	2644.00	2700.00	2667.00
472	18	25	20	60	32	2291.00	2287.50	2344.50	2307.67

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
473	41	3	18	52	44	2156.00	2136.00	2196.00	2162.67
474	22	53	26	53	49	-72.50	-84.00	-30.50	-62.33
475	45	15	16	25	39	3022.00	-7017.50	3032.50	-321.00
476	46	24	26	29	56	1024.00	972.50	-9050.00	-2351.17
477	29	10	12	29	32	4393.00	-5609.50	4449.00	1077.50
478	17	0	18	48	47	3575.00	-6486.00	3562.50	217.17
479	33	24	50	52	39	163.50	120.50	170.50	151.50
480	9	22	26	52	39	2658.00	2641.50	2660.00	2653.17
481	6	48	19	62	50	828.00	780.50	839.00	815.83
482	46	14	28	33	63	885.50	827.50	885.50	866.17
483	33	11	12	11	39	4722.50	-5311.00	-5301.50	-1963.33
484	41	25	53	61	41	-979.00	-989.50	-935.50	-968.00
485	45	9	28	33	39	2341.00	-7715.00	2335.00	-1013.00
486	46	15	16	25	63	1832.00	1790.00	1842.50	1821.50
487	15	28	18	53	63	1225.00	1239.00	1253.50	1239.17
488	2	35	19	19	61	3251.50	-6790.50	3262.50	-92.17
489	47	6	13	34	32	3408.50	-6616.50	3442.00	78.00
490	29	10	12	25	63	3130.50	3096.50	3160.50	3129.17
491	41	0	45	52	44	971.50	926.00	980.00	959.17
492	25	28	29	49	56	732.00	722.00	746.00	733.33
493	33	12	18	52	40	2298.50	2284.50	2339.50	2307.50
494	41	6	21	63	44	1310.50	1281.00	1338.50	1310.00
495	17	0	18	38	56	3631.00	-6429.50	-6450.00	-3082.83
496	46	15	34	48	46	622.00	574.00	625.00	607.00
497	16	6	16	30	39	4684.50	-5346.00	-5334.50	-1998.67
498	45	15	18	33	63	1385.50	1332.50	1385.00	1367.67
499	33	24	53	11	39	2023.00	-8024.50	2033.00	-1322.83
500	3	19	29	34	51	3269.00	-6800.00	3263.00	-89.33
501	33	5	7	32	47	3849.00	-6193.50	3861.00	505.50
502	33	16	29	24	47	2599.00	-7464.00	2590.00	-758.33
503	41	24	18	52	38	1411.50	1371.00	1431.50	1404.67
504	17	14	53	61	40	820.00	778.00	832.00	810.00
505	22	16	18	52	39	2706.00	2694.50	2749.50	2716.67
506	9	22	26	53	39	2609.00	2591.00	2610.00	2603.33
507	45	15	19	33	35	2678.00	-7366.00	2679.50	-669.50
508	6	48	19	60	50	928.00	881.00	939.50	916.17
509	17	25	19	27	61	2622.50	2594.00	2649.50	2622.00
510	2	31	18	54	63	1693.00	1649.50	1704.00	1682.17
511	16	6	16	27	47	4436.50	-5587.50	4463.50	1104.17
512	41	0	45	49	36	1504.50	1474.50	1533.00	1504.00
513	17	31	19	27	61	2314.00	2291.50	2349.50	2318.33
514	2	25	18	54	63	2001.50	1955.00	2015.50	1990.67
515	47	6	18	38	63	1486.00	1436.00	1492.50	1471.50
516	33	12	13	52	40	2552.50	2536.00	2592.00	2560.17
517	15	28	19	10	63	3290.50	-6743.50	3303.00	-50.00
518	34	10	13	38	63	2183.50	2144.50	2204.00	2177.33
519	17	15	19	19	39	4587.00	-5454.50	-5441.00	-2102.83
520	2	35	21	52	61	1533.00	1501.00	1554.50	1529.50

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
521	46	15	29	24	32	2706.00	-7325.50	2728.00	-630.50
522	33	16	16	25	48	3136.50	-6908.50	3143.00	-209.67
523	22	16	18	53	63	1484.50	1493.00	1503.00	1493.50
524	46	15	16	24	39	3021.00	-7013.00	3032.00	-320.00
525	18	25	21	61	32	2190.50	2187.00	2241.00	2206.17
526	17	14	52	60	40	919.50	878.50	937.50	911.83
527	22	24	17	52	39	2347.00	2338.50	2394.00	2359.83
528	46	15	18	52	38	1611.50	1578.50	1633.00	1607.67
529	45	15	18	33	63	1385.50	1332.50	1385.00	1367.67
530	41	6	22	63	44	1266.00	1235.00	1288.00	1263.00
531	9	20	29	50	39	2705.50	-7353.00	2701.00	-648.83
532	25	30	26	54	56	531.50	525.00	581.50	546.00
533	3	22	26	34	51	3269.00	-6791.00	3262.50	-86.50
534	9	19	29	53	39	2609.50	2596.50	2600.50	2602.17
535	33	48	7	32	47	1709.50	1672.00	1727.50	1703.00
536	6	26	19	60	50	2035.00	1996.00	2051.50	2027.50
537	23	32	19	31	44	2596.00	-7465.50	2589.50	-760.00
538	33	12	18	55	40	2151.00	2134.00	2194.00	2159.67
539	2	25	13	53	63	2306.00	2262.00	2313.00	2293.67
540	22	24	17	25	39	3659.50	-6364.50	3698.50	331.17
541	33	16	16	52	48	1809.50	1790.00	1843.00	1814.17
542	17	14	26	52	39	2657.50	2645.50	2700.00	2667.67
543	25	31	19	17	56	2641.50	-7412.00	2688.00	-694.17
544	46	25	16	24	39	2521.00	-7525.00	2529.50	-824.83
545	17	15	19	27	61	3131.00	-6936.50	3112.50	-231.00
546	9	22	19	27	39	4217.00	-5799.50	4262.00	893.17
547	17	27	29	50	61	880.00	883.50	896.50	886.67
548	42	25	22	63	44	274.00	265.50	323.00	287.50
549	17	6	21	61	32	3202.00	-6852.00	3207.00	-147.67
550	17	6	20	60	40	2925.50	2905.50	2956.00	2929.00
551	16	14	48	27	47	2442.00	-7610.00	2441.50	-908.83
552	34	12	13	52	40	2501.50	2495.00	2546.00	2514.17
553	33	10	13	38	63	2234.50	2195.50	2255.00	2228.33
554	17	15	18	52	63	1844.00	1804.00	1854.50	1834.17
555	41	16	18	53	38	1762.50	1731.00	1784.00	1759.17
556	45	15	21	63	47	526.00	525.50	577.00	542.83
557	41	6	18	33	60	2167.50	2140.50	2199.00	2169.00
558	17	29	12	25	63	2775.00	2750.50	2805.50	2777.00
559	29	8	19	27	61	2876.50	2848.50	2908.00	2877.67
560	41	0	37	49	36	1904.50	1878.50	1936.00	1906.33
561	3	22	18	34	51	3657.50	-6388.00	3665.50	311.67
562	14	19	29	53	39	2354.00	2343.00	2402.00	2366.33
563	6	5	19	60	50	3108.50	3061.50	3072.50	3080.83
564	2	36	29	52	61	1070.50	1046.50	1098.50	1071.83
565	17	28	21	50	61	1218.50	1232.00	1245.00	1231.83
566	17	6	20	52	40	3316.00	-6747.50	3311.50	-40.00
567	33	16	16	60	48	1410.00	1382.50	1441.00	1411.17
568	17	12	18	55	63	1848.00	1806.00	1856.50	1836.83

Trials	Aircraft Number by Type					Fitness Value			Total
Trials	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Fitness
569	33	15	18	52	40	2147.50	2133.00	2192.00	2157.50
570	14	19	28	27	61	2625.50	2597.00	2656.50	2626.33
571	17	15	18	53	39	2961.50	2943.00	2951.00	2951.83
572	41	0	19	49	36	2791.50	-7258.00	2795.50	-557.00
573	6	5	37	60	50	2194.00	2161.00	2215.00	2190.00
574	41	6	12	25	60	2867.50	2844.00	2898.50	2870.00
575	29	10	18	33	63	2433.50	2402.00	2456.50	2430.67
576	17	31	19	17	56	3025.50	-7006.00	3055.50	-308.33
577	25	14	26	52	39	2247.50	2234.00	2294.50	2258.67
578	17	24	17	26	39	3863.50	-6155.50	3901.50	536.50
579	22	29	12	25	63	2518.00	2503.00	2546.50	2522.50
580	29	10	12	27	61	3129.00	3101.00	3109.50	3113.17
581	29	8	19	25	63	2878.50	2849.00	2909.00	2878.83
582	9	22	13	39	39	3939.00	-6096.00	3958.50	600.50
583	33	10	19	26	63	2522.50	2499.00	2553.50	2525.00
584	33	48	7	40	47	1318.00	1276.00	1326.00	1306.67
585	14	19	29	61	39	1960.50	1936.00	2001.50	1966.00
586	45	15	22	63	47	476.00	470.00	527.00	491.00
587	42	25	21	63	44	324.00	316.00	373.00	337.67
588	2	36	2	52	61	2450.00	2404.50	2464.50	2439.67
589	29	10	19	25	63	2777.00	2747.00	2807.00	2777.00
590	33	10	19	27	40	3565.00	-6459.50	3597.50	234.33
591	33	15	18	53	63	968.00	989.00	1038.00	998.33
592	29	10	13	52	61	1837.00	1795.00	1850.00	1827.33
593	34	12	12	27	40	3767.00	-6258.50	3803.50	437.33
594	17	9	20	51	40	3214.00	-6848.50	3205.50	-143.00
595	29	7	19	27	61	2927.50	2899.00	2959.00	2928.50
596	33	48	7	47	44	1118.00	1069.00	1124.50	1103.83
597	42	25	21	56	47	526.00	518.50	528.50	524.33
598	29	10	18	35	48	3058.00	-7005.50	3053.50	-298.00
599	33	16	16	62	63	568.00	584.00	642.00	598.00
600	9	22	19	25	39	4311.00	-5699.00	4356.50	989.50
601	29	8	13	39	63	2492.00	2450.00	2510.50	2484.17
602	35	6	18	38	63	2082.50	2044.00	2103.50	2076.67
603	46	12	13	52	40	1915.00	1878.00	1931.50	1908.17
604	41	6	12	26	60	2818.50	2793.50	2848.50	2820.17
605	25	14	26	55	39	2100.00	2089.50	2144.00	2111.17
606	17	6	13	55	63	2411.50	2367.50	2421.50	2400.17
607	41	12	19	25	60	2227.50	2188.00	2246.00	2220.50
608	17	19	29	61	39	1805.50	1789.50	1844.50	1813.17
609	9	29	12	24	63	3231.00	-6845.50	3208.00	-135.50
610	17	15	18	53	59	1991.50	1953.50	2009.00	1984.67
611	33	15	7	47	44	2760.00	2738.50	2799.50	2766.00
612	33	48	18	53	63	-664.50	-682.50	-624.00	-657.00
613	17	9	13	55	63	2256.50	2210.00	2267.50	2244.67
614	17	0	18	53	39	3716.00	-6340.00	3710.50	362.17
615	22	12	21	50	61	1786.50	1750.50	1805.50	1780.83
616	46	28	19	25	60	1177.50	1124.00	1184.50	1162.00

Trials	Aircraft Number by Type					Fitness Value			Total
	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Fitness
617	29	12	12	27	40	4014.00	-5999.00	-6000.00	-2661.67
618	46	9	20	51	40	1764.00	1727.00	1785.00	1758.67
619	6	14	29	52	61	1999.50	1954.50	2014.50	1989.50
620	29	36	5	55	39	1865.50	1826.50	1885.00	1859.00
621	14	10	12	27	61	3876.00	-6176.50	3869.50	523.00
622	29	19	28	27	61	1880.50	1837.50	1895.00	1871.00
623	29	10	13	54	63	1638.00	1594.50	1649.50	1627.33
624	29	10	19	27	61	2775.00	2746.50	2801.50	2774.33
625	6	5	26	60	50	2753.00	2714.00	2767.00	2744.67
626	25	13	37	55	39	1609.50	1586.00	1634.50	1610.00
627	22	16	18	53	38	2705.00	2694.00	2749.00	2716.00
628	34	6	19	27	61	2724.00	2695.00	2755.50	2724.83
629	33	15	18	38	63	1720.00	1689.50	1747.00	1718.83
630	19	6	18	53	59	2350.00	2308.00	2365.00	2341.00
631	17	6	12	26	61	3977.50	-6080.50	3969.50	622.17
632	57	5	37	60	51	-421.50	-430.00	-375.50	-409.00
633	46	12	29	59	40	769.00	724.50	774.50	756.00
634	17	19	13	50	39	3157.50	-6901.50	-6900.00	-3548.00
635	8	22	19	25	39	4357.50	-5648.50	4407.00	1038.67
636	63	26	37	54	48	-1323.50	-1331.50	-1286.50	-1313.83
637	57	37	21	48	11	1284.50	-8736.00	1308.00	-2047.83
638	52	25	54	22	6	1985.50	-7998.50	-7990.50	-4667.83
639	49	22	52	22	38	867.00	-9179.50	872.50	-2480.00
640	26	15	24	43	2	4439.00	-5536.00	-5521.00	-2206.00
641	42	17	26	51	19	2255.00	-7781.50	2274.50	-1084.00
642	45	18	19	35	58	1331.50	1284.50	1337.00	1317.67
643	60	48	63	16	50	-1813.00	-11876.00	-1780.50	-5156.50
644	25	14	21	44	44	2658.00	2639.50	2694.50	2664.00
645	35	35	5	40	23	3103.00	-6926.00	3126.00	-232.33
646	14	19	32	36	31	3407.50	-6606.50	3447.50	82.83
647	17	48	10	49	1	3699.50	-6289.50	-6274.50	-2954.83
648	58	0	52	23	30	1849.50	-8182.50	1874.00	-1486.33
649	46	26	12	8	58	2542.00	-7510.50	2547.50	-807.00
650	29	59	60	2	4	2168.50	-7755.50	-7741.50	-4442.83
651	3	29	36	30	48	2748.50	-7299.00	2752.50	-599.33
652	18	8	36	50	61	1433.50	1394.00	1454.00	1427.17
653	46	2	42	46	35	1493.50	1471.50	1526.50	1497.17
654	33	32	43	10	53	1488.50	-8568.00	1488.00	-1863.83
655	4	35	8	3	48	5145.00	-4899.50	-4887.00	-1547.17
656	19	35	44	29	4	3398.00	-6600.00	-6574.50	-3258.83
657	45	5	47	41	62	85.50	72.50	128.50	95.50
658	4	18	42	60	37	2010.00	1993.50	2051.00	2018.17
659	3	43	43	8	59	2242.50	-7801.50	2249.00	-1103.33
660	63	4	14	12	63	2245.50	2239.50	2292.50	2259.17
661	26	48	32	56	63	-1165.00	-1183.00	-1125.50	-1157.83
662	19	19	50	28	13	3509.50	-6483.00	-6467.00	-3146.83
663	8	2	7	3	51	6523.50	-3535.50	-3516.00	-176.00
664	56	30	13	26	7	3351.00	-6652.00	-6635.00	-3312.00

Trials	Aircraft Number by Type					Fitness Value			Total
	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Fitness
665	33	57	9	57	13	1547.50	-8491.50	1570.50	-1791.17
666	14	19	40	36	31	3000.50	-7008.50	3044.50	-321.17
667	25	14	29	44	44	2251.50	2235.50	2290.50	2259.17
668	26	48	36	8	56	1340.50	-8716.50	1386.00	-1996.67
669	3	43	47	56	60	-366.50	-372.50	-317.00	-352.00
670	49	22	50	29	38	630.00	-9426.50	667.50	-2709.67
671	19	19	52	23	13	3658.00	-6337.00	-6317.50	-2998.83
672	3	29	37	33	48	2551.50	-7505.00	2546.00	-802.50
673	42	17	27	12	44	2930.50	-7112.00	2937.50	-414.67
674	8	2	7	3	48	6660.00	-3390.00	-3365.50	-31.83
675	63	4	14	12	60	2393.50	2390.00	2441.50	2408.33
676	61	0	52	23	30	1699.50	-8332.50	1722.50	-1636.83
677	26	59	60	2	4	2323.50	-7605.50	-7591.50	-4291.17
678	45	2	42	41	62	485.50	477.50	496.00	486.33
679	46	5	47	46	35	1098.50	1068.00	1129.50	1098.67
680	56	30	12	35	56	628.50	568.00	628.50	608.33
681	45	18	18	26	5	4345.00	-5641.00	-5625.00	-2307.00
682	63	26	37	54	44	-1127.50	-1131.00	-1088.50	-1115.67
683	25	1	21	44	48	3124.50	3099.50	3107.00	3110.33
684	35	35	36	55	23	829.00	809.50	870.50	836.33
685	18	8	5	45	61	3256.50	3214.50	3271.00	3247.33
686	46	2	42	41	62	435.50	426.50	440.00	434.00
687	45	5	47	46	35	1148.50	1118.50	1180.00	1149.00
688	38	32	43	10	53	1238.50	-8819.00	1276.00	-2101.50
689	46	4	14	12	60	3228.00	-6798.00	3252.00	-106.00
690	63	5	47	46	35	248.50	218.50	271.50	246.17
691	36	35	36	55	23	779.00	759.00	820.00	786.00
692	45	17	27	12	44	2780.50	-7264.50	2787.00	-565.67
693	5	19	40	36	31	3455.00	-6558.50	3501.00	132.50
694	17	59	3	2	4	5618.00	-4301.50	-4286.00	-989.83
695	57	32	43	15	11	2056.00	-7950.50	-7935.00	-4609.83
696	38	37	10	53	53	530.00	523.50	576.50	543.33
697	45	5	47	44	44	815.50	771.50	826.50	804.50
698	25	14	21	46	35	2983.50	-7056.00	2995.50	-359.00
699	63	7	5	44	63	985.50	977.00	1032.00	998.17
700	18	11	14	13	61	4216.00	-5830.00	4216.00	867.33
701	26	13	42	41	62	885.50	834.00	891.00	870.17
702	46	0	24	43	2	4192.50	-5784.00	-5774.00	-2455.17
703	46	26	10	41	58	1033.00	1020.00	1038.50	1030.50
704	45	2	44	8	62	1994.50	1987.00	2046.00	2009.17
705	17	11	47	50	61	768.00	781.50	789.50	779.67
706	3	40	5	39	60	2738.50	2700.50	2755.00	2731.33
707	49	22	51	3	49	1332.50	-8717.50	1332.00	-2017.67
708	4	35	9	29	39	4223.00	-5800.50	4257.50	893.33
709	25	14	28	44	44	2302.50	2286.00	2340.50	2309.67
710	2	2	44	8	62	4174.00	-5883.00	4172.00	821.00
711	43	35	9	29	39	2284.00	-7772.50	2281.50	-1069.00
712	39	30	12	35	56	1478.50	1428.50	1481.50	1462.83

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
713	49	26	10	41	58	883.00	872.50	882.50	879.33
714	32	7	5	39	60	2941.50	2902.00	2962.50	2935.33
715	3	42	47	46	35	1398.50	-8671.50	1430.50	-1947.50
716	22	14	29	44	44	2405.50	2387.50	2447.50	2413.50
717	7	2	7	3	48	6707.50	-3333.50	-3319.00	18.33
718	18	8	7	50	61	2909.50	2868.00	2921.50	2899.67
719	17	11	45	45	61	1123.00	1094.00	1147.50	1121.50
720	45	17	27	44	48	1022.50	973.00	1032.00	1009.17
721	38	1	21	12	44	4228.00	-5806.50	4249.50	890.33
722	46	4	14	44	60	1668.50	1637.50	1695.50	1667.17
723	63	7	5	12	60	2693.50	2687.50	2743.00	2708.00
724	46	5	47	44	44	765.50	720.50	776.00	754.00
725	45	26	10	41	58	1083.00	1025.50	1079.50	1062.67
726	5	19	41	44	31	3010.50	-7005.50	3049.50	-315.17
727	25	14	28	36	44	2694.00	-7356.00	2696.50	-655.17
728	25	14	42	61	35	1212.50	1176.00	1234.50	1207.67
729	4	45	21	47	37	2345.50	-7714.00	2342.50	-1008.67
730	17	59	42	41	59	-816.50	-830.00	-780.50	-809.00
731	26	13	3	2	1	-2422.50	-2296.50	-2274.50	-2331.17
732	45	18	21	53	5	2876.00	-7133.50	2922.50	-445.00
733	38	37	13	26	53	1715.50	1675.00	1731.00	1707.17
734	25	1	20	36	47	3604.50	-6443.00	3608.50	256.67
735	25	14	29	44	51	1913.50	1892.50	1941.50	1915.83
736	18	8	4	44	44	4168.00	-5890.50	4164.50	814.00
737	25	14	31	50	61	1017.50	1031.00	1049.00	1032.50
738	32	7	5	44	63	2547.50	2502.00	2562.50	2537.33
739	63	7	5	39	60	1384.00	1329.50	1382.00	1365.17
740	22	8	7	50	60	2752.50	2715.00	2767.50	2745.00
741	18	14	29	44	45	2561.50	2546.50	2601.00	2569.67
742	38	37	13	45	53	779.50	765.00	786.00	776.83
743	17	11	45	26	61	2067.00	2042.50	2102.00	2070.50
744	22	14	2	44	44	3755.00	-6294.50	3758.00	406.17
745	45	26	21	22	58	1471.00	1425.50	1486.50	1461.00
746	4	45	21	35	37	2925.00	-7112.00	2941.00	-415.33
747	25	14	45	46	35	1798.50	1778.00	1835.50	1804.00
748	32	22	51	7	60	1443.00	1431.00	1492.00	1455.33
749	49	7	5	35	49	2800.50	2787.50	2846.00	2811.33
750	49	27	14	41	58	633.00	620.00	645.50	632.83
751	46	5	10	44	60	1821.50	1789.00	1847.00	1819.17
752	16	7	5	45	61	3410.00	3366.50	3421.00	3399.17
753	61	8	5	12	60	2743.50	2738.00	2793.50	2758.33
754	45	26	47	44	44	-234.50	-284.00	-234.00	-250.83
755	46	13	21	53	5	3076.00	-6932.00	3124.00	-244.00
756	18	2	44	45	61	1587.50	1546.00	1606.00	1579.83
757	2	8	5	8	62	5850.00	-4222.00	-4205.00	-859.00
758	38	63	41	44	28	-673.50	-690.50	-639.50	-667.83
759	5	18	21	12	47	4904.00	-5144.50	-5136.00	-1792.17
760	36	32	36	55	23	929.00	910.00	971.50	936.83

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
761	25	1	21	35	39	3984.00	-6042.00	4006.00	649.33
762	4	45	20	36	45	2545.00	-7509.50	2546.00	-806.17
763	33	14	45	44	63	135.50	130.00	181.50	149.00
764	24	7	5	46	35	4191.50	-5848.50	4206.00	849.67
765	41	14	2	46	58	2022.50	1989.50	2048.00	2020.00
766	18	26	21	20	44	3564.00	-6458.00	3600.50	235.50
767	36	32	36	53	61	-815.50	-828.00	-774.00	-805.83
768	17	11	45	24	23	3960.00	-6020.00	-6007.50	-2689.17
769	39	6	11	35	56	2722.50	2693.50	2748.50	2721.50
770	32	31	5	44	63	1335.50	1328.50	1345.50	1336.50
771	18	2	44	47	61	1486.50	1450.50	1505.50	1480.83
772	32	22	51	2	60	1691.50	-8362.50	1701.50	-1656.50
773	18	8	5	35	48	4365.50	-5687.00	4366.00	1014.83
774	49	7	4	44	45	2602.00	2590.00	2639.50	2610.50
775	63	8	5	39	60	1334.00	1278.50	1331.50	1314.67
776	22	7	7	50	60	2804.00	2760.50	2819.50	2794.67
777	18	2	10	45	61	3309.50	3266.00	3321.00	3298.83
778	46	8	5	44	60	1922.50	1889.00	1942.00	1917.83
779	18	14	29	12	63	3248.00	-6791.50	3263.50	-93.33
780	61	8	5	35	45	2359.00	2333.50	2387.50	2360.00
781	49	27	5	41	58	1083.00	1069.50	1093.50	1082.00
782	16	7	14	45	61	2953.00	2918.00	2970.50	2947.17
783	45	24	5	44	44	1965.50	1937.50	1981.50	1961.50
784	16	5	47	45	61	1383.50	1343.00	1397.50	1374.67
785	33	63	41	44	28	-423.50	-10485.00	-388.50	-3765.67
786	16	7	5	45	63	3313.50	3267.50	3323.00	3301.33
787	18	14	29	12	61	3346.50	-6691.50	3363.00	6.00
788	39	23	51	2	35	2511.50	-7531.50	-7514.00	-4178.00
789	33	37	13	45	53	1029.50	974.00	1028.00	1010.50
790	25	14	29	45	61	1372.00	1338.50	1396.50	1369.00
791	46	8	7	51	60	1467.50	1480.50	1489.50	1479.17
792	41	14	0	45	58	2176.00	2140.50	2199.00	2171.83
793	16	5	45	46	61	1434.50	1394.00	1453.50	1427.33
794	48	7	5	45	61	1771.00	1748.00	1796.00	1771.67
795	29	8	5	35	45	3945.00	-6094.00	3957.00	602.67
796	24	6	29	46	35	3035.50	-7004.50	3053.00	-305.33
797	25	15	6	44	51	3029.00	3003.00	3053.00	3028.33
798	16	7	13	44	63	2956.00	2914.00	2971.50	2947.17
799	32	31	6	45	61	1334.50	1327.50	1335.00	1332.33
800	46	7	5	44	44	2753.50	2741.50	2791.50	2762.17
801	50	24	4	44	45	1717.50	1679.50	1729.00	1708.67
802	39	6	11	39	23	4092.00	-5913.50	4141.00	773.17
803	17	11	45	28	56	2210.00	2197.00	2250.50	2219.17
804	18	26	21	43	44	2451.50	2441.50	2491.50	2461.50
805	18	2	44	16	61	3000.00	-7047.00	3009.00	-346.00
806	21	7	7	53	60	2706.50	2666.00	2719.50	2697.33
807	17	8	5	35	48	4412.00	-5636.50	4417.50	1064.33
808	18	2	10	44	39	4403.00	-5641.50	4414.50	1058.67

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
809	25	1	21	34	61	2990.00	2955.00	3015.00	2986.67
810	63	8	5	39	61	1284.50	1233.50	1286.50	1268.17
811	48	7	4	44	45	2653.50	2635.50	2695.50	2661.50
812	18	26	45	46	61	284.50	277.00	300.50	287.33
813	17	11	45	28	45	2735.00	-7309.00	2749.50	-608.17
814	29	8	5	35	56	3431.50	-6641.00	3460.50	83.67
815	21	7	7	50	60	2855.00	2816.50	2869.50	2847.00
816	41	14	0	42	58	2326.00	2291.00	2350.00	2322.33
817	24	6	25	45	35	3289.00	-6752.50	3299.50	-54.67
818	32	31	3	46	61	1434.00	1428.50	1446.00	1436.17
819	45	7	5	44	61	1977.00	1940.50	1994.00	1970.50
820	48	7	5	45	44	2601.50	2585.00	2644.50	2610.33
821	49	27	2	45	61	884.50	873.50	930.00	896.00
822	25	14	26	41	58	1874.00	1845.50	1899.50	1873.00
823	45	26	21	43	44	1115.00	1069.00	1130.50	1104.83
824	17	7	5	44	44	4220.00	-5840.00	4216.50	865.50
825	17	13	20	36	44	3548.00	-6500.00	3557.00	201.67
826	4	43	45	28	57	1225.00	1189.50	1242.00	1218.83
827	17	5	47	45	48	1967.00	1944.50	2000.00	1970.50
828	16	8	5	35	61	3840.50	-6230.50	3821.00	477.00
829	21	7	7	50	60	2855.00	2816.50	2869.50	2847.00
830	16	24	5	42	61	2694.00	2656.50	2707.00	2685.83
831	62	8	5	39	61	1334.50	1279.50	1332.00	1315.33
832	31	15	6	44	51	2724.00	2693.00	2749.00	2722.00
833	45	26	21	45	61	184.50	170.00	229.00	194.50
834	25	1	21	36	44	3694.00	-6344.00	3707.00	352.33
835	16	13	21	45	63	2197.50	2151.50	2212.00	2187.00
836	17	7	4	36	44	4657.50	-5388.50	4668.00	1312.33
837	48	7	4	45	60	1871.50	1838.50	1891.50	1867.17
838	21	7	7	51	45	3529.50	-6544.00	3519.00	168.17
839	18	7	5	12	61	4933.00	-5134.00	4923.50	1574.17
840	21	14	31	53	60	1121.50	1132.50	1147.00	1133.67
841	24	11	45	28	45	2399.00	-7663.00	2387.00	-959.00
842	17	6	25	45	35	3631.00	-6399.50	3660.00	297.17
843	16	4	10	44	39	4403.50	-5641.50	4415.00	1059.00
844	18	2	13	44	63	3109.50	3066.00	-7000.00	-274.83
845	16	15	5	45	63	2903.50	2867.00	2919.00	2896.50
846	31	7	5	44	51	3181.00	3154.50	3209.00	3181.50
847	25	14	26	45	58	1674.00	1640.00	1698.50	1670.83
848	48	7	4	40	45	2849.50	2832.00	2896.00	2859.17
849	62	7	5	44	61	1134.50	1133.00	1136.50	1134.67
850	17	8	5	39	44	4406.00	-5639.50	4416.00	1060.83
851	16	15	5	44	61	3050.50	3011.50	3069.50	3043.83
852	48	7	5	29	44	3377.50	-6660.00	3392.50	36.67
853	46	13	8	51	59	1233.00	1231.00	1244.50	1236.17
854	18	7	5	45	61	3308.00	3270.00	3321.00	3299.67
855	16	7	5	42	61	3557.50	3517.50	3534.50	3536.50
856	16	24	5	45	61	2545.50	2501.00	2561.50	2536.00

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
857	45	14	0	42	58	2118.00	2088.50	2146.00	2117.50
858	25	8	5	35	56	3631.00	-6439.00	3617.50	269.83
859	31	7	5	28	45	4237.50	-5794.00	4257.00	900.17
860	55	11	45	29	44	848.50	822.50	873.00	848.00
861	25	1	21	36	45	3646.00	-6394.00	3657.50	303.17
862	22	7	7	51	44	3526.50	-6540.00	3508.00	164.83
863	16	7	4	45	61	3461.00	3417.00	3471.00	3449.67
864	48	7	5	40	45	2799.00	2791.50	-7250.00	-553.17
865	25	14	26	44	51	2066.50	2039.00	2093.00	2066.17
866	31	7	5	45	58	2793.00	2761.50	2812.50	2789.00
867	45	14	0	41	61	2020.00	1989.00	2046.50	2018.50
868	32	31	3	45	58	1632.50	1589.00	1641.50	1621.00
869	18	2	5	42	63	3610.50	3565.00	3577.00	3584.17
870	16	7	13	44	61	3053.00	3013.50	3070.50	3045.67
871	46	8	8	51	59	1466.50	1480.00	1488.50	1478.33
872	31	2	5	44	51	3431.00	3402.00	3459.50	3430.83
873	30	5	47	45	48	1323.00	1282.00	1339.50	1314.83
874	22	8	5	35	56	3780.50	-6286.50	-6300.00	-2935.33
875	16	13	21	44	63	2247.50	2207.00	2262.50	2239.00
876	16	4	10	45	39	4358.50	-5691.50	-5700.00	-2344.33
877	62	7	5	12	61	2694.50	2688.00	2744.00	2708.83
878	18	7	5	44	61	3357.00	3315.00	3371.00	3347.67
879	17	7	4	10	44	5952.00	-4096.50	-4077.00	-740.50
880	21	14	31	36	60	1975.50	1942.50	2001.50	1973.17
881	16	15	5	44	63	2953.00	2912.50	2969.00	2944.83
882	16	15	5	45	61	3001.00	2961.50	3019.50	2994.00
883	16	7	5	45	50	3934.00	-6136.50	3917.00	571.50
884	16	7	4	45	60	3509.00	3466.50	3520.00	3498.50
885	48	7	4	45	61	1822.00	1788.50	1846.50	1819.00
886	16	11	45	29	45	2737.50	-7303.50	2745.50	-606.83
887	55	24	5	45	60	634.00	626.00	678.50	646.17
888	31	14	0	41	61	2741.50	2704.50	2760.00	2735.33
889	45	7	5	45	58	2075.00	2040.00	2099.00	2071.33
890	21	14	30	44	51	2069.00	2039.50	2099.50	2069.33
891	25	14	27	37	60	1923.50	1901.50	1950.00	1925.00
892	16	7	7	45	50	3831.00	-6237.50	3816.00	469.83
893	46	8	10	51	59	1367.50	1389.00	1392.00	1382.83
894	62	8	5	12	61	2644.50	2642.50	2688.50	2658.50
895	21	14	30	45	61	1529.00	1490.50	1549.50	1523.00
896	16	15	4	36	60	3543.00	3508.50	3526.00	3525.83
897	18	2	16	42	63	3056.00	-7050.00	3071.50	-307.50
898	30	5	58	45	48	773.00	727.50	786.00	762.17
899	16	20	13	44	63	2295.50	2260.50	2311.00	2289.00
900	16	7	5	44	61	3459.50	3417.00	3470.50	3449.00
901	31	14	5	44	51	2825.50	2794.00	2855.00	2824.83
902	21	2	30	44	51	2680.00	2653.50	2709.00	2680.83
903	16	3	2	44	61	3810.00	-6279.50	3774.50	435.00
904	18	25	16	42	63	1883.00	1843.00	1897.00	1874.33

Trials	Aircraft Number by Type A1	A2	A3	A4	A5	Fitness Value Scenario1	Scenario2	Scenario3	Total Fitness
905	25	62	21	36	45	610.00	574.00	619.50	601.17
906	16	7	15	41	61	3099.50	3067.00	3119.00	3095.17
907	31	14	2	44	61	2491.00	2448.50	2504.00	2481.17
908	16	7	4	45	63	3364.50	3318.00	3373.00	3351.83
909	48	13	21	44	61	734.50	726.00	740.00	733.50
910	32	23	5	12	58	3530.50	-6497.00	3553.50	195.67
911	62	31	3	45	61	-15.50	-28.50	25.00	-6.33
912	16	7	5	13	61	4987.00	-5083.00	4975.00	1626.33
913	62	7	5	43	61	1184.50	1178.50	1202.00	1188.33
914	25	14	27	36	60	1973.00	1951.50	2000.00	1974.83
915	16	15	11	37	60	3141.00	3110.00	3166.00	3139.00
916	19	8	5	50	61	2959.50	2918.50	2971.50	2949.83
917	22	4	45	29	45	2788.50	-7250.00	2795.50	-555.33
918	16	7	10	42	61	3304.00	-6800.00	3320.50	-58.50
919	45	2	5	44	61	2235.00	2195.00	2254.50	2228.17
920	18	7	5	42	63	3358.50	3316.00	3372.00	3348.83
921	29	7	5	45	58	2893.50	2857.50	2914.00	2888.33
922	47	14	0	46	61	1671.50	1636.00	1693.00	1666.83
923	19	14	2	44	61	3100.00	3061.50	3119.00	3093.50
924	31	8	5	50	61	2344.00	2301.00	2356.50	2333.83
925	16	7	13	18	61	4327.00	-5726.50	4325.00	975.17
926	22	4	37	2	45	4529.00	-5504.50	-5494.50	-2156.67
927	21	2	27	45	63	2199.50	2153.00	2213.50	2188.67
928	16	7	1	44	51	4140.00	-5934.00	4121.00	775.67
929	18	7	4	45	60	3407.00	3365.00	3420.00	3397.33
930	31	7	5	45	58	2793.00	2761.50	2812.50	2789.00
931	17	7	5	45	61	3359.00	3315.50	3371.00	3348.50
932	63	24	5	43	58	433.00	416.50	474.50	441.33
933	16	14	0	45	60	3354.50	3313.50	3370.50	3346.17
934	47	7	4	46	61	1823.00	1789.00	1847.00	1819.67
935	31	14	2	44	50	3025.00	3000.50	3056.50	3027.33
936	31	14	5	44	60	2387.50	2346.50	2402.00	2378.67
937	16	7	15	42	61	3050.00	3017.50	3069.50	3045.67
938	18	25	16	41	63	1933.00	1893.50	1947.50	1924.67
939	21	2	30	45	63	2042.50	2001.50	2057.00	2033.67
940	19	7	5	43	51	3827.50	-6237.50	3815.00	468.33
941	18	23	5	10	63	4109.50	-5935.50	4118.00	764.00
942	32	2	5	44	58	3043.50	3008.50	3065.00	3039.00

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Vita

Major Bennett was born in St. Louis, Missouri. He graduated from Bitburg American High School in Bitburg, Germany in June 1982. He entered undergraduate studies at the University of Missouri in Rolla, Missouri where he graduated with a Bachelor of Science degree in Aerospace Engineering in December 1986. He received his commission through AFROTC DET 440A, at the University of Missouri-Rolla.

His first assignment was as an airframe propulsion integration project engineer at the NASA-Langley Research Center, Hampton, VA in October 1987. In September 1989, he was assigned to the Arnold Engineering Development Center (AEDC), Arnold AFB, Tennessee where he served as an aerospace test facility manager, aerospace systems test manager, and as a manager, space requirements and facility planning. In March 1994, he entered Undergraduate Missile Training at Vandenberg AFB, California where he was recognized as a Distinguished Graduate. In July 1994, he was assigned to F. E. Warren AFB, Wyoming where he served as a Minuteman III ICBM Deputy Combat Crew Commander, Minuteman III ICBM Combat Crew Commander, Minuteman III ICBM Stan/Eval Crew Commander, Minuteman III ICBM Flight Commander/Instructor, and Minuteman III ICBM Operations Support Flight Commander/Instructor.

In August of 1998, he entered the Graduate Operations Research Program, School of Engineering and Management, Air Force Institute of Technology, Wright-Patterson AFB, Ohio. Upon graduation, Maj. Bennett will be assigned to the Pentagon.